Building Salt Marshes Along the Coasts of the Continental United States

by

W. W. Woodhouse, Jr.

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This is the first comprehensive report on coastal marsh creation in the United States. This report provides potential users an analysis and interpretation of the available information on this subject. The role of marshes, the feasibility of marsh creation, and the effects of elevation, salinity, slope, exposure, and soils on marsh establishment are discussed. Plants suitable for marsh building are described by the major regions. Plant propagation, planting, fertilization, and management of the major plants are discussed. Labor and material requirements for marsh creation are summarized.

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PREFACE

This report provides coastal engineers and others with comprehensive information on salt marsh creation in the United States.

This is one of a series of reports to be published to form a Coastal Engineering Manual.

The report was prepared by W.W. Woodhouse, Jr., Professor of Soil Science, North Carolina State University, under CERC Contract No. DACW72-76-C-0006.

The author expresses appreciation to J.M. Carlton, C.L. Newcombe, W.C. Sharp, H.J. Teas, and J.W. Webb for their helpful suggestions; to S.W. Broome, J. Colosi, and E.D. Seneca for their review and comments.

P.L. Knutson was the contract monitor of the report under the general supervision of E.J. Pullen, Chief, Coastal Ecology Branch, Research Division.

Comments on this publication are invited.

Approved for publication in accordance with Public Law 166, 79th Congress, approved 31 July 1945, as supplemented by Public Law 172, 88th Congress, approved 7 November 1963.

Ted E. Bishop

TED E. BISHOP
Colonel, Corps of Engineers
Acting Commander and Director

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CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	by	To obtain
inches	25.4	millimeters
	2.54	centimeters
square inches	6.452	square centimeters
cubic inches	16.39	cubic centimeters
feet	30.48	centimeters
	0.3048	meters
square feet	0.0929	square meters
cubic feet	0.0283	cubic meters
yards	0.9144	meters
square yards	0.836	square meters
cubic yards	0.7646	cubic meters
miles	1.6093	kilometers
square miles	259.0	hectares
knots	1.852	kilometers per hour
acres	0.4047	hectares
foot-pounds	1.3558	newton meters
millibars	1.0197×10^{-3}	kilograms per square centimeter
ounces	28.35	grams
pounds	453.6	grams
	0.4536	kilograms
ton, long	1.0160	metric tons
ton, short	0.9072	metric tons
degrees (angle)	0.01745	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins[1]

[1]To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use formula: $C = (5/9)(F - 32)$.
To obtain Kelvin (K) readings, use formula: $K = (5/9)(F - 32) + 273.15$.

GLOSSARY

ERGOT - a dark, spongy, parasitic mass found on the ovaries of various grasses.

IRREGULARLY FLOODED - areas of the shoreline which are not covered and uncovered by the rise and fall of the tide on a daily basis, but are subject to flooding during extreme lunar tides or wind setup. Generally, the region between mean high water and the estimated highest tide.

PRIMARY PRODUCTIVITY - the rate at which energy is stored by photosynthesizing organisms (chiefly green plants) in the form of organic substances.

PLANT PROPAGATION - increase in number, or multiplication, of plants to perpetuate the species or variety. Also the process and methods employed by man to promote natural increase in some plants and to bring increase about under conditions when it would not otherwise take place.

PLUG - a root-soil mass with attached aerial stems of living plants. A type of PROPAGULE.

PROPAGULE - a plant material such as seeds, SPRIGS, or seedlings used in PLANT PROPAGATION.

REGULARLY FLOODED - areas of the shoreline which are usually covered and uncovered by the daily rise and fall of the tide. Generally, the region between mean low water and mean high water.

SPRIG - a part of a plant consisting of at least one node (joint of a stem from which the leaves arise) with attached stems and roots of living plants. A type of PROPAGULE.

BUILDING SALT MARSHES ALONG THE COASTS OF THE CONTINENTAL UNITED STATES

by
W. W. Woodhouse, Jr.

I. INTRODUCTION

1. Natural Marsh.

A coastal marsh is a herbaceous plant community (plants lacking woody stems) found on the part of the shoreline which is periodically flooded by sact or brackish water. A number of species in the grass family (gramineae), sedge family (cyperaceae), and rush family (juncaceae) commonly form coastal marshes.

Coastal marshes occur naturally in the intertidal zone of moderate to low-energy shorelines along tidal rivers and in bays and estuaries. These marshes may be narrow fringes along steep shorelines, but can extend over wide areas in shallow, gently sloping bays and estuaries. Such lands were extensive and widely distributed along the Atlantic, gulf, and Pacific coasts of the United States before development by man.

Until recently, these wetland resources have been steadily shrinking as they were generally considered useless and viewed as prime areas for agricultural, commercial, and recreational uses and for waste disposal. For example, since 1850 an estimated 1,000 square kilometers of wetlands have been diked and filled in California alone (U. S. Army, Engineer District, San Francisco, 1976).

Destruction of coastal wetlands has lessened as the value of these areas as nursery grounds or sources of primary production (energy) for a high proportion of sports and commercial fishery species (Odum, 1961; Teal, 1962; Odum and de la Cruz, 1967; Cooper, 1969; Williams and Murdock, 1969) and the need for shoreline protection has become widely recognized.

Interest has developed in marsh restoration, in the building of new marshes to replace a part of those that have been lost, and in the use of marsh plants to stabilize and protect eroding shorelines. Studies on marsh building were initiated in North Carolina in 1969 under the sponsorship of the Coastal Engineering Research Center (CERC) (Woodhouse, Seneca, and Broome, 1972, 1974, and 1976) and later expanded to the Chesapeake Bay (Garbisch, Woller, and McCallum, 1975) and the gulf coast (Dodd and Webb, 1975; Webb and Dodd, 1976). Studies of marsh building along the Pacific coast were undertaken in 1975 (Knutson, 1975; U. S. Army Engineer District, San Francisco, 1976; Knutson, 1976). These studies, and earlier plantings along tidal river shores in Virginia (Sharp and Vaden, 1970), have demonstrated the feasibility of establishing new coastal marsh under a variety of situations.

Various aspects of marsh creation are currently being studied. The U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, has made marsh-building tests on dredged material at several widely distributed locations. Garbisch (1977) identified 105 sites where experimental or applied marsh plantings had been attempted. Data are available from a limited number of sites primarily on the Atlantic, gulf, and central (San Francisco Bay) California coasts. Consequently, the information will require considerable extrapolation and many of the resulting recommendations will be speculative. However, marsh creation in suitable situations offers real promise; it cannot become a fully established practice until carried beyond the experimental and demonstrational stage.

This study provides potential users an analysis and interpretation of the current information on marsh creation along the coasts of the continental United States, including the Great Lakes.

2. Types of Coastal Marshes.

There are two major groups of coastal salt marshes in the United States, based on physiographic differences -- marshes of the Atlantic and gulf coasts and those characteristic of the Pacific coast. The east coast marshes usually form on a gently sloping coast with a broad continental shelf, under conditions of a sea slowly rising relative to the land. West coast marshes are mostly formed in relatively narrow river mouths which drain almost directly onto a steeply sloping continental shelf along a slowly emerging coastline (Cooper, 1969). Consequently, the west coast estuaries and their marshes are more limited in development than those of the east coast and tend to mature more rapidly.

Coastal salt marshes are also divided into regularly flooded low marsh, which is considered to be the most valuable, and irregularly flooded high marsh.

a. East Coast Marshes. Vegetation of east coast marshes is remarkably uniform. The intertidal zone from New England to Texas is dominated by a single species, smooth cordgrass (*Spartina alterniflora*) (Fig. 1). Two grasses, saltmeadow cordgrass (*S. patens*) and saltgrass (*Distichlis spicata*), usually dominate the zone immediately above high tide along these coasts with two rushes on slightly higher sites -- black-grass (*Juncus gerardi*) north of the Virginia Capes and black needle rush (*J. roemerianus*) southward (Fig. 2).

East coast marshes divide into three general types: New England, mid-Atlantic, and South Atlantic and gulf. Typical New England marshes occur on fibrous or silty peat because the shore is predominantly composed of hard rock. The intertidal zone of pure stands of smooth

Photo courtesy of S. W. Broome

Figure 1. Typical intertidal low marsh of smooth cordgrass.

Figure 2. High marsh of black needle rush (background) and short form of smooth cordgrass (foreground).

cordgrass is usually relatively narrow with a well-developed upper zone of saltmeadow cordgrass mixed with saltgrass. Saltmeadow cordgrass often occupies a larger area than smooth cordgrass. Pure stands of black-grass in the higher parts of the zone often form a fringe at the edges of the uplands.

Marshes in the mid-Atlantic region undergo subtle changes from the New England type on Long Island to the South Atlantic type at the Virginia Capes. There are relatively limited areas of smooth cordgrass with the greatest area covered by saltmeadow cordgrass. Localized high salinity patches are dominated by pickleweed (*Salicornia spp.*) Big cordgrass (*Spartina cynosuroides*) and several rushes (*Scirpus spp.*) occur along creeks and tidal stream mouths where the freshwater influence is greater. Black needle rush increases in importance near the mouth of the Chesapeake Bay. The tall form of smooth cordgrass appears along creek banks.

South of the Chesapeake Bay, the South Atlantic and gulf coast marshes typically form behind barrier beaches and in estuaries where rivers deposit heavy silt burdens. Smooth cordgrass occupies vast areas of mostly soft sediments between mean sea level (MSL) and mean high water (MHW). Large areas of high marsh, primarily black needle rush, occur where astronomical tides are restricted and wind setup predominates; e.g., in Pamlico Sound, North Carolina. South of Daytona Beach, Florida, the typical South Atlantic marshes are largely replaced by mangrove trees that form the tropical and subtropical equivalent of salt marshes. Marshes of the South Atlantic type occur on the northeast, north, and west gulf coasts with the largest expanses on the Mississippi River delta. Smooth cordgrass occupies the areas regularly flooded by saltwater with brackish marsh of saltmeadow cordgrass, saltgrass, and black needle rush covering vast areas. Gulf cordgrass (*Spartina spartinae*) replaces saltmeadow cordgrass above MHW on fine-textured soils along the coasts of Texas and southwestern Louisiana. Hypersaline conditions in the Laguna Madre, due to limited rainfall and high temperatures, largely exclude coastal marshes from the south Texas coast. Black mangroves (*Avicennia germinans*) occasionally appear southward of Galveston and on offshore islands farther north.

b. West Coast. Vegetation on the west coast marshes is less uniform than on the east coast. Pacific cordgrass (*Spartina foliosa*), the west coast equivalent of smooth cordgrass, occurs only along the central and southern California coasts. Pickleweeds, which are widely distributed but of little importance on the east coast, are major plants along the west coast. Sedges (*Carex spp.*), arrowgrass (*Triglochlin maritima*), and tufted hair grass (*Deschampsia caespitosa*) become important northward of the range of Pacific cordgrass. Saltgrass occurs all along the west coast, but as on the east coast, it is seldom dominant over much area (Cooper, 1969; Jefferson, 1973).

c. Great Lakes. Shorelines are generally steeply sloped and, if exposed to open waters, are subject to a similar wave climate as the exposed seacoasts of the North Atlantic. Consequently, the Great Lakes marshes are of limited extent, confined to the protected shores of bays and inlets. The marshes are largely limited to Lake Michigan and Lake Huron (Hall and Ludwig, 1975). Marsh plants are freshwater species with a few plants such as common reed (*Phragmites communis*) (Fig. 3) which also occur in brackish marshes.

Figure 3. Common Reed.

3. Value.

Salt marshes are valued as sources of primary production and as nursery grounds for sport and commercial fishery species. They stabilize and protect shorelines, provide turbidity control and a damping effect upon storm surges, and store and recycle nutrients and pollutants such as nitrogen, phosphorus, and heavy metals.

a. Productivity.

(1) Primary Production (Energy). Tidal marshes can be extremely productive. Primary production is carried out by two groups of plants, the marsh grasses (or other vascular plants) and the algae on living and dead plants and on the surface of the marsh mud. Cooper (1969) summarized data on productivity and energy flow in low marsh of smooth cordgrass typical of the Georgia coast. This is the most complete study of salt marsh available and these marshes are some of the most productive. Along creek banks where growth is greatest, annual net production of the grass was as high as 22,000 kilograms of biomass per hectare, equaling or exceeding the highest yielding food and forage crops of the world. Net production of the short grass in higher marshes away from the creeks was much lower, about 6,000 kilograms per hectare. Net production from algae added about 500 kilograms per hectare. Average net production for the marsh as a whole, considering the relative areas in the different types, was about 16,000 kilograms per hectare. These amounts are typical of the more productive east coast low marshes but stunted forms of the same species elsewhere may have net production of 2,000 kilograms per hectare or less, only 10 percent of that of the most productive marshes. Also, along the Atlantic coast, production by smooth cordgrass decreases from south to north. This is not true of all marsh species (Reimold and Linthurst, 1977).

(2) Utilization. Little of the biomass of salt marsh, about 5 percent, is consumed while the plant material is still living (Fig. 4). Grasshoppers and planthoppers graze on the grass and are, in turn, eaten by spiders and birds. Direct consumption of rhizomes and culms of marsh grasses by wild fowl may be significant locally near wintering grounds. Periwinkles graze on algae growing on the grass. The majority of the energy is believed to move through the detrital food chain. Dead grass is broken down by bacteria in the surrounding waters and on the surface of the marsh. This process greatly decreases the total energy but increases the concentration of protein, thereby increasing the food value. Some detrital particles and mud algae are eaten by a variety of detritus feeders such as fiddler crabs, snails, and mussels; these organisms are, in turn, eaten by mud crabs, rails, and raccoons. The remaining detritus, augmented by the dead matter from the primary and secondary consumers, is washed from the marsh by tidal action as new export. This exported detritus, with material from submergent aquatic plants and the plankton, feeds the myriads of larvae and mature fish and shellfish which use estuaries, bays, and adjoining shallow waters. Marsh grasses may account for most of the primary production of the system in waters where high turbidity reduces light penetration, thereby reducing phytoplankton and submergent aquatic production.

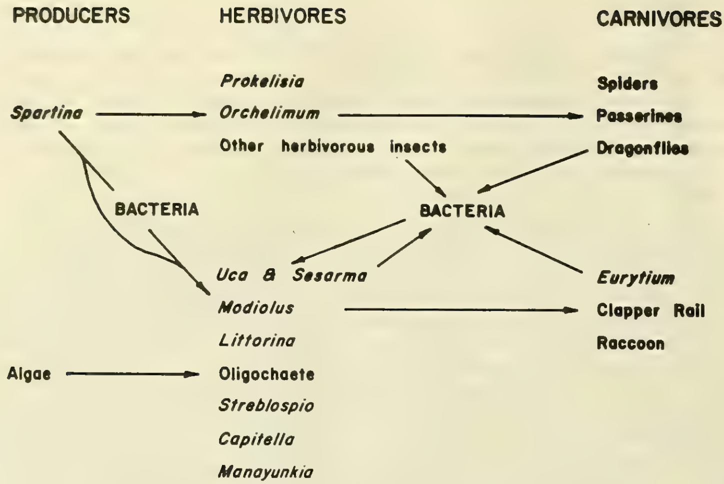

Figure 4. Georgia low marsh food web (redrawn from Teal, 1962).

The productivity and utilization of high marsh has received less attention than that of low marsh. Indications are that net production of some high marsh may equal that of many low marsh. The important difference, however, is that the export mechanism of frequent tidal flushing is absent in high marsh. Consequently, much of the high marsh biomass goes into peat formation, in situ, rather than into the estuarine food chain. For this reason, high marsh appears to be of much less direct value to the estuary although it is effective for shore stabilization and damping of storm surges.

(3) Marsh Animals. The rigorous environment of the salt marsh sharply limits the number of animals that live there. These areas are used by birds such as herons, rails, sandpipers, geese, ducks, and songbirds and by raccoons. A much larger population of animals lives in or on the mud surface. The more conspicuous are fiddler crabs, mussels, clams, and periwinkles. Less obvious but more numerous are annelid and oligochaete worms and insect larvae.

In addition, larvae, junveniles, and adults of many shellfish and fish are commonly found in the marsh creeks.

Little is known of the animal populations and the feeding relationships in the high marsh.

b. Protection. Quantitative documentation on the value of marsh vegetation in reducing shore erosion is limited to a few recent plantings. However, a number of these plantings have demonstrated that the development of a full cover of marsh grasses can reduce or eliminate erosion by trapping sediments and damping the impact of waves (Woodhouse, Seneca, and Broome, 1974, 1976; Garbisch, Woller, and McCallum, 1975) (Figs. 5, 6, and 7). More information will be available as the number of experimental and applied plantings increases. Many stable estuarine shorelines have a natural protective cover of marsh vegetation. Also, the natural stabilization of the intertidal fringes of dredged material deposits in bays and estuaries by vegetation has long been observed.

Marshes are by no means impervious to erosion. They are particularly vulnerable to undercutting below the waterline and may be overcome by persistent high-energy wave action. The older, high marsh becomes very susceptible to erosion as it builds up a thick layer of peat which elevates the living marsh. This often results in the development of a vertical scarp and the progressive undermining of the marsh edge. Thousands of kilometers of *Juncus* marsh in the estuaries of the South Atlantic and gulf coasts are presently eroding; large areas of high marsh have been lost in this way (Fig. 8).

The value of the damping action of marsh vegetation on the movement of water entering bays and estuaries as a result of storm surges is difficult to assess. The effect is small where marsh occupies a narrow fringe along steep shorelines but can be substantial in large, shallow, gently sloping marsh areas.

c. Nutrient Cycling. Salt marshes have substantial absorptive capacities for potential pollutants such as nitrogen, phosphorus, and heavy metals (Williams and Murdock, 1969; Woodhouse, Seneca, and Broome, 1974). Increased growth of salt marsh species, particularly smooth cordgrass, in response to nutrients has been noted at several locations (Valiela and Teal, 1974; Woodhouse, Seneca, and Broome, 1974; Garbisch, Woller, and McCallum, 1975; Patrick and Delaune, 1976; Mendelssohn, in preparation, 1978). Under some circumstances, smooth cordgrass will increase growth in response to applications of as much as 672 kilograms of nitrogen and 74 kilograms of phosphorus per hectare per year as fertilizer (Woodhouse, Seneca, and Broome, 1974, 1976). Apparent recovery of applied nitrogen may be as high as 40 to 60

Photo courtesy of S.W. Broome

Figure 5. Shoreline sloped and planted with smooth cordgrass (left) and saltmeadow cordgrass (right), planted 10 May (photo taken 15 June 1976). Plants established and beginning new growth.


Photo courtesy of S.W. Broome

Figure 6. Erosion under control on planted slope 4 months after planting, and erosion continuing on unplanted slope (photo taken 1 September 1976).

Figure 7. Planted slope stabilized and unplanted continuing to erode, after 19 months (photo taken 9 November 1977).

Figure 8. Erosion scarp along edge of smooth cordgrass-needle rush marsh growing on peat.

percent in shoot growth alone, a figure that compares favorably with upland field crops. The potential for substantial recycling and exporting of nutrients to the estuary exists.

The absorption, conversion, and recycling abilities of marsh plants offer real opportunities for improving water quality (Woodhill, 1977).

d. <u>Sediment Accumulation</u>. Marshes perform a valuable role in trapping sediments, thereby reducing turbidity in bays, sounds, and estuaries. Turbidity reduction is highly beneficial in protecting shellfish beds from excessive siltation and increasing light penetration which promotes phytoplankton production. Chapman (1938) estimates accretion rates in New England salt marshes to be 0.1 to 0.4 centimeter per year and Ranwell (1964) reported an average value of 0.2 to 1.0 centimeter per year for temperate European marshes. Higher rates probably occur in certain marshes growing in sediment-rich

waters such as those of some estuaries in the southeastern United States.

II. SITE REQUIREMENTS

1. Elevation.

Elevation and the tidal regime determine the degree, duration, and timing of submergence. These, in turn, largely determine the location and type of marsh. However, there does not appear to be a simple relationship for submersion, marsh location, and development. For example, low marsh may occur (a) under regular diurnal tide cycles, two lows and two highs approximately equal in magnitude daily, typical of much of the Atlantic coast; (b) where water level is largely controlled by wind setup, and tides may remain high or low for days at a time; and (c) under mixed semidiurnal cycles of two different highs and two different lows, daily, as in San Francisco Bay, plus numerous variations of these. Thus, the controlling factor from the standpoint of water levels may be the average daily submergence period, the longest period of continuous submergence, certain wind-induced, extended periods of submergence or exposure, or some combination of these. Consequently, the best estimates of suitable elevations for marsh building at any given site are obtained by observing nearby natural marsh. Lacking this, trial plantings extending between points well above and well below the estimated final elevations should be made and the survival determined. Where planting on large, relatively flat areas, trial plantings are needed to establish the suitable planting elevations. The lower limit is usually well defined. On smaller plantings, allowances are made by overlapping the most probable adaptation limits. Estimated adaptation limits are presented by species in the planting techniques, Section IV, 3.

2. Slope.

Slope determines the area suitable for marsh growth. Productive marshes are found over a very wide range of slopes; however, either an excessive or an insufficient slope can have important effects on marsh establishment and growth. Steep slopes facilitate drainage and aeration but are more difficult to plant, more resistant to natural colonization by marsh species, and limit the area that can support marsh. In addition, waves dissipate their energy over a short distance when meeting on abrupt shoreline. On a gradual-sloping shoreline, wave energy will dissipate over a longer distance. Very gradual slopes impede circulation and drainage and are usually less productive due to bare salt slicks or pannes and large areas of stunted plant growth. Much of the so-called short form of smooth cordgrass occupies essentially flat areas. On filled or graded slopes, uneven settling

or grading creates poorly drained pockets that become an increasing problem as slope decreases.

Slopes from 10 percent to less than 1 percent have been successfully planted. Slopes of 1 to 3 percent are preferable as long as surface drainage is not impeded.

3. Exposure.

Exposure to wave action is a major factor in determining the feasibility of marsh establishment along any exposed shoreline. Marsh plants can withstand low to moderate levels of wave energy characteristic of many sites in sounds, bays, and estuaries, but cannot grow and persist under high-energy conditions. For example, marshes are not found on the open coasts of the Atlantic and Pacific Oceans and the Great Lakes.

Preliminary marsh-building design criteria have recently been advanced and are based on limited data (Woodhouse, Seneca, and Broome, 1972, 1974, 1976; Garbisch, 1977; Knutson, 1977). Research is continuing on this subject. In the meantime, some rough rule of thumb is necessary. Wave climate, as determined by wind speed and direction, bottom and shoreline configuration, water level, and fetch, is a dominating factor in determining site suitability. However, the absence of information on the tolerance of marsh plantings to specific wave climates and the difficulty of forecasting wave climate for specific sites, make it necessary to rely on more general indexes. Fetch is probably the most readily determined and the most meaningful available. It must be used with caution, always keeping in mind the modifying effect of other factors.

Although marsh plantings were reported as early as 1948 (Sharp and Vaden, 1970), most plantings were done from 1969 to 1976: 19 on the northeast Atlantic coast, 20 in the Chesapeake Bay, 19 on the southeast Atlantic coast, 20 on the gulf coast, and 10 on the Pacific coast. Successful establishments of sprigs or plugs were recorded at fetches of less than 4 kilometers in North Carolina and the Chesapeake Bay, and at a maximum fetch of 2 kilometers in Texas and California (San Francisco Bay). Seeding has been successful in North Carolina and Chesapeake Bay when the fetch is less than 1 kilometer. Much depends on the timing of individual storms. The critical period is during establishment. Storms that will eliminate fresh transplants or young seedlings may have no effect on established stands. Also, wave action during high water may be above much of the plantings with damage confined to the upper part where it can be more readily tolerated. Consequently, experience with the same site can vary greatly from year to year.

The amount of fetch that may be tolerated by marsh plantings varies with the alinement of the site in relationship to the direction of the strong winds, wind velocities, and the seasonal timing of the winds as well as nearshore topography, tidal currents, species, and type of substrate. In general, sites open to fetches in excess of 4 or 5 kilometers should not be planted with sprigs or plugs, and unprotected sites exposed to fetches over 1 kilometer should not be seeded.

III. MARSH SOILS

1. Types.

Coastal marshes grow on a wide variety of substrates, on mineral soils from coarse sands to fine clays, and peats and mucks of varying organic matter content and degree of decomposition. Marsh growth and productivity is favored by high mineral content of the substrate (DeLaune, Buresh, and Patrick, in preparation, 1979). At least a part of this effect appears to be due to the higher concentration of nutrients in most mineral soils. The predominantly organic soils may contain equal amounts of nutrients on a dry weight, but much less on a volume basis. Sands are usually much lower in nutrients than are silts and clays (Woodhouse, Seneca, and Broome, 1974; Garbisch, Woller, and McCallum, 1975).

Planting is easiest on sandy soils. These are more likely to have adequate bearing strength and provide sufficient traction for machine planting. The opening and closing of planting holes or furrows is also easier in sandy substrates. The principal disadvantage of this type of soil is the low nutrient content. This may not constitute a serious handicap in nutrient-rich waters but becomes acute enough, in some cases, to require the use of fertilizers to assure rapid establishment.

Silts and clays usually contain ample nutrients for normal growth of marsh species and usually support the most productive marshes. They are not, however, always easy to plant. Some are too soft for machinery and others are too stiff for the opening and closing of planting holes. Planting holes may have to be opened with an auger in some compact silts and clays and float-out of fresh transplants is more common with these soils. Planting in extremely soft materials can cause problems in the approach to planting and in keeping plants or seeds in place until they can securely anchor themselves. Excessive softness is common in recently deposited, fine-grained dredged materials. Overly compacted soils are more common along eroding shorelines.

Although large areas of marsh grow on organic substrates, these are generally the least desirable soils for planting. Most of the marsh situated on organic substrates is the result of peat formation in place under the growing marsh. The marsh was probably established before peat formation began. Organic soils and particularly fibrous peats are very difficult materials, both physically and chemically, in which to plant marsh species. The mechanics of opening and particularly closing planting holes or furrows are difficult. Nutrient deficiencies result in slow growth and poor survival. Direct seeding of such sites is next to impossible since the seedbeds do not retain seed long enough to allow germination and establishment.

2. Salinity.

Salinity is the one common factor that affects all salt marsh plants. These plants must have some salt tolerance, a prime requirement in this habitat. Some of the more tolerant species have the capacity to excrete salt through special structures (salt glands) in their leaves. A number of them possess another mechanism in their roots for screening toxic ions and slowing absorbtion (Waisel, 1972).

Plants of the regularly flooded, low marshes, such as smooth cordgrass, Pacific cordgrass, and the mangroves, are well equipped to live and grow in salinities up to 35 parts per thousand (sea strength). However, these plants are usually quicker to establish and more productive in salinities below sea strength. Seeds and young seedlings are usually more sensitive to salt concentration than are established plants.

Relatively little work has been done on salinity regimes of marsh soils and their effect on plants under field conditions. Soil salinity is not easy to investigate because of the high variability, in time and space, of salt concentrations. The concentration of salt required to eliminate a particular species from a site need not occur often or persist for more than a few hours or days. Consequently, these events may elude fairly intensive sampling.

Toxic concentrations usually do not develop in sandy marsh soils within the regularly flooded zone. The free water salinity in such soils tends to remain close to that of the surrounding water. This may not always be true of fine-textured soils in which salt may accumulate through ion exclusion by roots (Smart and Barko, 1978), although it does not appear to be a common occurrence in natural marshes. Salt accumulation in the fine-textured marsh soils is probably held to a minimum by the drainage normally provided by root channels and animal burrows.

Salt damage may develop on newly planted or seeded areas due to concentration through evaporation in the zone between neap tide high water and spring tide high water during periods of low rainfall and warm temperatures following spring tides. This also occurs in sounds and bays subject to wind setup in which the wind pattern results in extended periods of low water during hot weather; e.g., in Core Sound, North Carolina. Under these conditions, soil water salinities of 50 to 75 parts per thousand may develop and persist until diluted by rainfall or tidal inundation (Woodhouse, Seneca, and Broome, 1974).

Irregularly flooded, high marshes are subject to occasional salt buildup through evaporation and ion exclusion, regardless of soil texture However, this is usually limited to poorly drained areas that are flooded by storm tides. In humid climates precipitation plus freshwater seepage from higher ground tends to keep salinities in most high marshes well below sea strength. Under more arid conditions, salt concentrations often exclude marsh species altogether.

Recently deposited sediments such as dredged materials are subject to the same processes as the soils of established marshes once they are populated by plants. Consequently, salt contents of sandy materials in the intertidal zone are not likely to impede establishment of locally adapted marsh species. Salt buildup may delay or prevent plant establishment on irregularly flooded sites, particularly when sandy materials are exposed to periods of low rainfall and high temperatures just before and following planting. Domes of sandy material adjacent to and above marsh plantings tend to reduce salt damage by accumulating precipitation which seeps outward, lowering salt concentration in the planting zone.

Salt retention by freshly deposited, fine-textured dredged materials may become a deterrent to marsh establishment. This is suggested by a greenhouse test using a tidal simulation system (Barko, et al., 1977; Smart and Barko, 1978). The problems inherent to the extrapolation of greenhouse results to field conditions might be expected to be magnified here. However, these data could help in explaining salt damage in new plantings. Areas of salt buildup were found in recently planted intertidal salt marsh with dying of plants when salinity reached 45 parts per thousand (Woodhouse, Seneca, and Broome, 1974). These spots appeared to be related to segregation and stratification of fine-textured sediments contained in dredged spoil.

3. Oxygen-Aeration.

Marsh soils are, by nature, chronically or periodically flooded and are, therefore, usually poorly to very poorly aerated. The severity and duration of this varies with such factors as topographic position, soil texture, and water regime as well as the biological activity in the soil. Oxygen is supplied to these soils by oxygen-bearing water and plants growing on them. Parts of intertidal marsh soils may be drained and aerated at each ebbtide if the internal drainage allows appreciable emptying of pores during these brief intervals of exposure.

Similarly, parts of high marsh soils may become aerated during periods of dry weather and low water tables.

Most sediments, such as freshly deposited dredged materials, will be highly anaerobic or low in oxygen. However, this does not prevent the establishment of adapted marsh species. These plants have various adaptations to an anaerobic environment. For example, certain intertidal species have anatomical features that enable their leaves to supply oxygen to their roots (Teal and Kanwisher, 1966; Anderson, 1974; Kasapligil, 1976). Smooth cordgrass and probably many others utilize ammonia, which is the usual form of nitrogen under anaerobic conditions, more efficiently than the nitrate form, usually preferred by upland species (Gosselink, 1970; Woodhouse, Seneca, and Broome, 1976; Mendelssohn, in preparation, 1979).

Some intertidal species contribute to the aeration of soils by releasing oxygen from their roots. This has been demonstrated for Pacific cordgrass under controlled conditions and in the field (Pride and Lingle, 1976; Wong, 1976). The evidence of it in the form of oxidized (yellowish or brown) zones around the roots and rhizomes of smooth cordgrass has been frequently observed. Oxygen supplied in this way promotes the activity of other organisms and eventually contributes to improved internal drainage and increased aeration. From a practical marsh-building point of view, the scarcity of oxygen in marsh soils appears to be unimportant. There is no evidence that it will prevent the establishment of marsh plants on sites that are otherwise suitable. Anaerobic conditions affect the growth of marsh plants by favoring the maintenance of nitrogen in the ammonia form and promoting the availability of such elements as iron and manganese by maintaining them in a reduced form. There probably are detrimental effects but little is known about them. Iron toxicity may occur because of the excessive availability of this element under highly anaerobic conditions. Similar effects may occur with other elements or compounds but these have not limited marsh creation.

Some dredged materials contain toxic substances that may interfere with plant growth and will need to be covered with uncontaminated material for marsh planting. Marsh areas may be underlain by "cat clays" (clays which are high in reduced sulphur) (Gallagher, Plumley, and Wolf, 1977). These become extremely acid through the oxidation of the sulphur when exposed to the atmosphere. Dredged material of this type, placed above mean sea level (MSL), must be covered with other soil to permit plant growth.

IV. MARSH PLANTS

1. Kinds and Adaptations.

A wide variety of plants can grow under marshy conditions where the water is fresh or only mildly brackish. This report emphasizes

the plants that, at present, appear useful in coastal marsh creation. The small number of these plants is due to the saline conditions prevailing in most coastal marshes, the rigorous conditions during establishment, the difficulties encountered in propagating some species, the lack of information available on others, and the secondary role a number of the plants play in stabilization and productivity. A great deal is known about where and under what conditions many marsh plants grow. Interest in planting them is of recent origin and planting requirements are known for only a few. More species are likely to be found useful in the future.

For marsh-planting purposes, the coasts of the continental United States are divided into the Atlantic, Peninsular Florida, Gulf of Mexico, North Pacific, South Pacific, and the Great Lakes. The Atlantic coast extends from the Canadian border to south of Jacksonville, Florida, where it grades into the Florida segment. The peninsular Florida coast begins here where mangroves start to invade salt marsh, extending around the peninsular Florida Keys to about the Suwannee River on the Gulf of Mexico. The gulf coast is a long and rather variable stretch extending from the Suwannee River around the gulf to the Mexican border. The Pacific coast is divided into the North Pacific section from about northern California to the Canadian border; the South Pacific section extends from north of San Francisco southward to Mexico. The Great Lakes coasts include the sheltered or semi-sheltered bays and inlets on all of the Great Lakes.

a. Atlantic Coast. This region encompasses a wide climatic range and a variety of secondary marsh species; however, the same species are planted throughout the region.

(1) Smooth Cordgrass (*Spartina alterniflora*). This is the dominant flowering plant in the regularly flooded intertidal zone along the Atlantic coast from Newfoundland to about central Florida (Fig. 9). These marshes are essentially pure stands of smooth cordgrass. This grass is well adapted to sea strength salinity (35 parts per thousand), excreting salt through salt glands in its leaves. The plant is also well adapted to the anaerobic substrates characteristic of most salt marshes. Its oxygen transport system consists of hollow, air-filled tissue, extending from openings in the leaves to the roots and rhizomes (Teal and Kanwisher, 1966; Anderson, 1974). Thus, oxygen reaches the below-ground tissues in anaerobic substrates. This grass can grow in a wide range of substrates from coarse sands to silty clays. Although dominant in regularly flooded, saline habitats, it is not restricted to these areas. It usually attains maximum growth under lower salinities (10 to 20 parts per thousand). The grass will grow and reproduce normally under freshwater conditions but is subject to increasing competition from other species as salinity declines (Woodhouse, Seneca, and Broome, 1972, 1974).

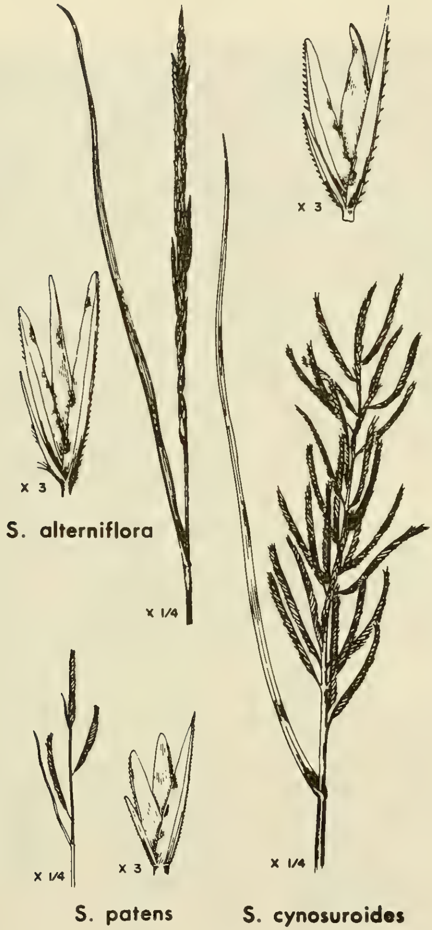

Figure 9. Atlantic and gulf coasts cordgrasses (reprinted from Beal, 1977).

Three distinct height forms (short, medium, and tall) covering a range of about 0.5 to 3 meters, have been widely recognized (Fig. 10). Within a natural marsh the tall form occurs along tidal creeks and drainage channels, and the short form on flat or very gently sloping areas away from the channels. The medium height form, when present, usually occupies a band between the tall and short forms. It is uncertain whether the differences in growth habit and productivity are due to genetic factors or the result of local environmental conditions. Earlier workers (Chapman, 1960; Stalter and Batson, 1969) suggested that the stunted form is a genetic variety. More recent greenhouse (Mooring, Cooper, and Seneca, 1971), biochemical (Shea, Warren, and Niering, 1972), and field transplant studies (Woodhouse, Seneca, and Broome, 1976) indicate that these differences are largely, if not altogether, environmental.

There are, however, distinct geographic populations of smooth cordgrass. Seneca (1974) grew plants from seeds collected from Plum Island, Massachusetts, to Port Aransas, Texas, under controlled conditions and in the field at Snow's Cut, North Carolina, and found that there were at least four groups differing in time of flowering, growth, reaction to photoperiod, culm (stem), and leaf color. Flowering progressed from north to south, growth was adapted to a progressively longer growing season north to south, and basal culm diameter and leaf width increased from north to south.

Vegetative reproduction by extensive below-ground, hollow stems (rhizomes) is the primary method of spreading in established stands. Although seed production is usually limited in old dense stands, it may be substantial in newly established stands and along margins such as the borders of tidal creeks. Seeds are important in spreading the plant into new areas and often contribute to thickening of open or patchy stands.

Smooth cordgrass has probably received more study and can be planted with better chance of success than any other coastal marsh species, native to the United States. It is relatively easy to propagate and quick to establish and spread. This grass tolerates inundation better than any other salt marsh species on the Atlantic and gulf coasts. Consequently, it is valuable in protecting the lower slope of spoil disposal areas and eroding shorelines.

(2) Saltmeadow Cordgrass (*Spartina patens*). This is a fine-leaved grass, 15 to 80 centimeters in height, that occurs extensively in the irregularly flooded high marsh zone all along the Atlantic Coast (Figs. 9 and 10). In the absence of black needle rush, it replaces smooth cordgrass at about the MHW level and forms dense mats from MHW to the high spring or storm tide line. This grass often forms a narrow band along the marsh edge but on gently sloping topography it may cover a wide expanse and be mixed with saltgrass, patches of needle rush, and other high marsh species. Saltmeadow cordgrass forms the

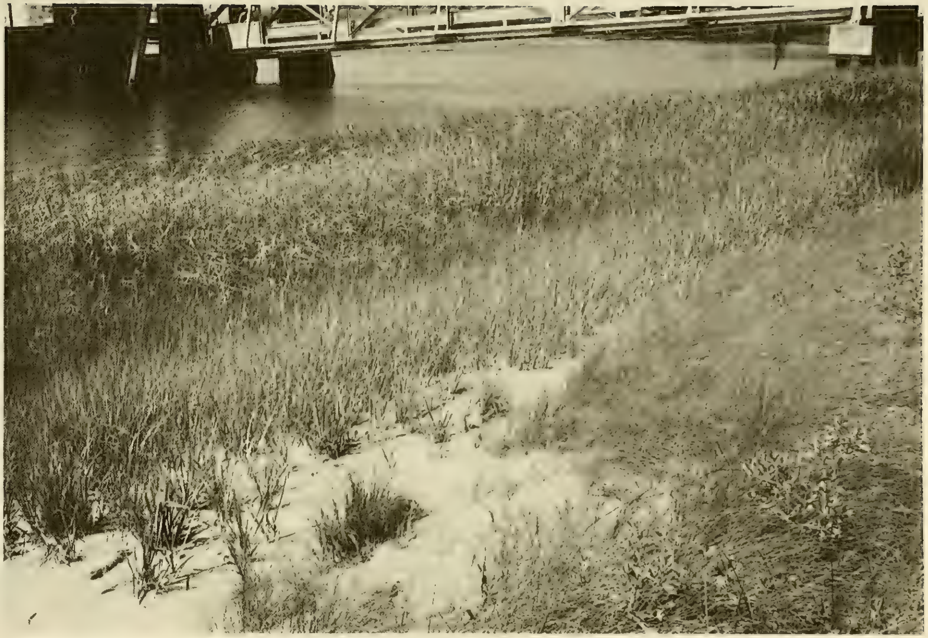

Figure 10. Narrow band of short form of smooth cordgrass (center) with tall form on the downslope side and saltmeadow cordgrass mixed with sea oxeye, upslope.

extensive saltmeadows of New England that were formerly mown for hay. This grass also occurs at higher elevations on sandflats and low dunes where growth is sparse. It has salt glands and is more salt-tolerant than typical dune species but less tolerant than smooth cordgrass.

Saltmeadow cordgrass can withstand extended periods of both flooding and drought, and often occurs where surface drainage is poor, causing ponding of rainwater during wet periods. It cannot tolerate the daily flooding of the intertidal zone. Productivity can be high but this species' contribution to the detrital food chain is much less direct than that of smooth cordgrass.

Saltmeadow cordgrass is a valuable stabilizer for the zone between the smooth cordgrass and the high spring or storm tide line or the zone of adaptation of the upland grasses such as tall fescue (*Festuca arundinacea*), bermuda (*Cynodon dactylon*), and St. Augustine (*Stenotaphrum secundatum*). It is relatively easy to multiply and transplant.

(3) Black Needle Rush (*Juncus roemerianus*). Black needle rush has stems and leaves that are round in cross section, rigid, with sharp-pointed tips capable of penetrating the skin (Figs. 2 and 11). Dense stands have a brown to gray-black appearance with little change in color throughout the year. Height ranges from 0.5 to 1.5 meters. This plant occurs extensively along the Atlantic coast south of New England as high marsh just above MHW, flooded only by wind-driven tides. It also grows in mixture with smooth cordgrass and saltmeadow cordgrass, and in extensive stands near the edge of the uplands where there is regularly seepage of freshwater. Productivity of black needle rush can be fairly high; however, there is little transfer of biomass from these marshes to the estuary as old growth tends to remain standing for 1 year or more. Much of the production goes into peat formation rather than the estuarine food chain. This plant is a good stabilizer. Although difficult to propagate, it readily invades areas stabilized by the cordgrasses wherever conditions favor it.

(4) Black-grass (*Juncus gerardi*). Stems of this rush grow 20 to 60 centimeters tall with leaf sheaths extending about halfway up the culm. Leaves are up to 20 centimeters long and are soft and green. Culms grow in small tufts. Rhizomes and stolons are slender, dark, and horizontally spreading. It has not been planted for marsh building but probably will volunteer where adapted.

(5) Saltgrass (*Distichlis spicata*). This grass is widely distributed in high marshes along the Atlantic coast. It is a low-growing grass (0.1 to 0.4 meter high), with a pale or whitish-green cast (Fig. 12). It is rarely dominant except in small poorly drained, more saline patches, and usually occurs mixed with saltmeadow cordgrass or rushes. Saltgrass is an effective stabilizer and is more salt tolerant than other high marsh species (Chabreck, 1972). It is more difficult to

Figure 11. Black needle rush surrounded by the short form of smooth cordgrass.

Figure 12. Saltgrass (reprinted from Beal, 1977).

establish than the cordgrasses but readily volunteers into areas first stabilized with other marsh plants. This and the fact that it is rarely dominant suggest that saltgrass should not normally be direct-planted but rather allowed to volunteer into those parts of a planting to which it is best adapted.

(6) Big Cordgrass (*Spartina cynosuroides*). This grass is taller (1 to 3 meters), with larger leaves, stems, and rhizomes than smooth cordgrass (Fig. 9). It grows in salty or brackish areas, above about MHW. Big cordgrass forms a dense root-rhizome mat and is a good stabilizer but not as effective as saltmeadow cordgrass; it dies back during cold weather. The grass covers large areas of high marsh along brackish shores such as in Currituck Sound, North Carolina. However, because it does not extend much below MHW, it cannot protect the lower slope and is often undermined by waves in that zone. Propagation of this plant is similar to smooth cordgrass but with much more difficulty. Consequently, like black needle rush and black-grass, indirect establishment of big cordgrass by planting other easier handled species such as smooth and saltmeadow cordgrass seems to be more practical.

(7) Common Reed (*Phragmites communis*). This large coarse grass is 1.5 to 4 meters tall and widely distributed in brackish to freshwater areas where it grows above about MHW (Fig. 3). Common reed seeds profusely, spreads vegetatively by rhizomes and stolons, is easy to transplant, and is a good stabilizer. Where adapted, it grows and spreads vigorously, often excluding other species. It is not generally favored as wildlife food or cover although it is eaten by muskrats. Since it can become a nuisance by crowding out more desirable plants, it should be introduced into new areas with extreme caution. It loses some stabilization ability when it dies back during the winter.

(8) Other Plants. Sea oxeye (*Borricha frutescens*), marsh elder (*Iva frutescens*), goldenrod (*Soldago spp.*), sea myrtle (*Baccharis halimifolia*), and mallow (*Hibiscus spp.*) are secondary plants of the high marsh. Most of these could be planted but will normally invade planted areas when and where conditions are favorable. Pickleweed and sea lavender (*Limonium spp.*) are common in the higher parts of the low marsh with pickleweed often in areas of salt concentration.

Saw grass (*Cladium jamaiecense*) occupies mildly brackish areas. Cattail (*Typha spp.*) is a common freshwater marsh species and has been planted for marsh building (Restick, Frederick, and Buckley, 1976). Arrow-arum (*Peltandra, spp.*) and pickerelweed (*Pontederia cordata*) have been planted with some success to form freshwater marsh (Garbisch and Coleman, 1978).

b. Peninsular Florida. Vegetation of the central and south Florida shorelines differs from that of the other shores. The intertidal zone in this region is usually dominated by mangrove trees rather than salt marsh. Mangroves play a role in stabilization and primary production

similar to that of temperate zone salt marshes and are generally considered their subtropical and tropical equivalents.

Established mangroves are very effective stabilizers (Carlton, 1974). The black mangrove produces extensive accessory root systems (pneumatophores) that form dense mats in and above the soil surface. The red mangrove (*Rhizophora mangle*) develops a system of prop roots which provides substantial trapping capacity. However, these tree species require considerably more time for complete establishment and are more difficult to establish on bare sites than are the grasses in the intertidal zone. Savage (1972) found that a minimum of 3 or 4 years is required for black mangrove seedlings to develop stabilizing roots; red mangroves require 5 or more years to develop prop roots. This can be cut in half by growing plants under controlled conditions (Howard Teas, Botanist, University of Miami, Coral Gables, Florida, personal communication, 1978). Even so, this means a period of at least 2 to 3 years from planting of mangrove seeds or seedlings to stabilization, compared with 9 to 14 months for smooth cordgrass. Also, the slow development of mangrove seedlings makes them much more vulnerable to damage or disturbance from wave and tidal action, floating debris, traffic, and browsing by animals and insects than most salt marsh species (Savage, 1972; Teas, Jergens, and Kimball, 1975). The alternative of planting 4- to 8-year-old plants, which have a better chance of survival, would be expensive and appears to be impractical except in small-scale, special purpose plantings.

Fortunately, a natural sequence along these shores is the initial stabilization of newly exposed intertidal sites by smooth cordgrass, followed by the invasion of mangrove seedlings. The smooth cordgrass is gradually overcome and eliminated through shading as the mangroves develop into trees (Lewis and Dunstan, 1975, 1976). Evidently, the mangrove seedlings establish more easily after the substrate has been stabilized by the grass.

The natural sequence of grass, followed by mangroves, offers a practical method of establishing vegetative cover in the intertidal zone. Stabilization can be accomplished rapidly and at low cost by planting smooth cordgrass. This will be followed on most sites by the natural invasion and eventual takeover of mangroves, if there is an adequate seed supply.

Planting of mangrove seed, seedlings, or plants in the cordgrass stand soon after stabilization would speed the transition, if desired.

(1) Mangroves. Three mangrove species occur along the Florida coast: the red mangrove (Fig. 13), the black mangrove (Fig. 14), and the white mangrove (*Laguncularia racemosa*) (Fig. 15). Red mangrove tolerates the deepest submersion, white mangrove the driest soil, and black mangrove the highest salinity. Black mangrove is the most cold-hardy but the slowest grower. White mangrove has the least cold

Photo courtesy of Marine Research Laboratory, Florida Department of Natural Resources

Figure 13. Red Mangrove showing aerial prop roots. Leaves are waxy, dark green on top and light green underneath.

Photo courtesy of Marine Research Laboratory,
Florida Department of Natural Resources

Figure 14. Black Mangrove with aerial pneumatophores. Leaves dark green above and silvery green below.

Photo courtesy of Marine Research Laboratory,
Florida Department of Natural Resources

Figure 15. White Mangrove (aerial roots are not usually noticeable). Leaves light, waxy green, above and below, with a pair of salt glands, appearing as black dots on each side of the petiole near the leaf proper.

tolerance and is the fastest growing (Davis, 1940; Savage, 1972; Pulver, 1976).

The red mangrove is well adapted to invade new areas through its large, viviparious seed (germinates within the pencillike radicle while still attached to the tree) which is ready to take root as soon as it falls from the tree. Propagules remain viable while floating long distances for months and take root upon landing on a suitable site. This is usually the first mangrove to invade new areas, and has been considered the chief agent for shoreline stabilization in Florida (Davis, 1940). The isopod parasite of mangrove roots (*Spaeroma terebrans*) causes serious damage to red mangroves on some sites (Teas, 1977).

Savage (1972) points out that black mangrove should be preferable for this purpose. It is more cold-hardy, more tolerant of artificial substrates and high-energy conditions, and provides earlier and more complete protection through the development of pneumatophores, than the other two species. White mangroves appear to have the lowest value for stabilization because the seedlings have more fragile root systems and are very slow to develop accessory roots. It invades and coexists with the other two and contributes to stability in this way.

The red mangrove usually fringes the shoreline. Apparently, this species is able to establish at slightly lower levels than the other two. All three are found growing at elevations from slightly below mean tide level (MTL) to well above MHW. Where both mangroves and salt marsh occur together, the mangroves extend seaward of the salt marsh. Mangroves, once established, can tolerate deeper water than salt marsh plants.

Mangroves easily form hedges along developed waterfront property. Savage (1972) found that all three species respond well to selective pruning. Thus, they can be used to replace or protect bulkheads and still fit landscaping plans, and can be pruned to avoid visual obstruction.

(2) Smooth Cordgrass. This is the dominant flowering plant in the regularly flooded intertidal zone in salt marsh along the coast of peninsular Florida. It is well adapted to sea strength salinity (35 parts per thousand). It will grow and reproduce in freshwater but will eventually be crowded out by other marsh and weedy species (Woodhouse, Seneca, and Broome, 1976). Other characteristics of this species are discussed in the Atlantic coast, Section IV, 1, a (1).

Whether the smooth cordgrass of peninsular Florida is distinct from that of the Georgia-north Florida marshes is unclear. It is probable that plants from farther north in Florida would perform satisfactorily here. This grass is most valuable in protecting the lower slope of spoil piles and eroding shorelines. It may be used very effectively to stabilize bare intertidal areas before the establishment of mangroves;

however, it will be shaded out by mangroves as they form a canopy.

(3) Saltmeadow Cordgrass. This grass occurs extensively in the irregularly flooded high marsh zone. Other characteristics are discussed in the Atlantic coast, Section IV, 1, a (2).

(4) Black Needle Rush. The characteristics of black needle rush have been discussed in the Atlantic coast, Section IV, 1, a (3).

(5) Saltgrass. This species is widely distributed in the more saline high marshes. Its characteristics have been discussed in the Atlantic coast, Section IV, 1, a (5).

(6) Big Cordgrass. This grass is taller, with larger leaves, stems, and rhizomes than smooth cordgrass. It grows in mildly brackish areas, upward from about MHW. Other characteristics of big cordgrass have been discussed in the Atlantic coast, Section IV, 1, a (6).

(7) Other Plants. There are a number of other species that occur in the salt marshes of peninsular Florida (Carlton, 1975, 1977). Sea lavender frequently occurs in the upper part of the low marsh. Pickleweed is common in low marsh areas of high salt concentration. Common secondary high marsh plants are sea oxeye (Figs. 16 and 17), marsh elder (Fig. 17), goldenrod, sea myrtle, torpedo grass (*Panicum repens*), St. Augustine grass, sea blight (*Suaeda, spp.*), and dropseed (*Sporobolus spp.*). Most of these can be planted, but they will usually invade planted areas when and where conditions favor their growth.

The introduced Australian pine (*Casuarina equisetifolia*) often induces erosion along steep shorelines by shading out the native marsh plants.

Saw grass forms large areas of low salinity marshes; cattails are major freshwater marsh plants. These are not, at present, planted for marsh building in Florida.

c. Gulf Coast. This is a long, highly variable coast, characterized by a low tidal range, particularly along the northwestern part. The low tidal range limits intertidal marshes to a narrow elevation zone and restricts saltwater penetration into many bays and estuaries. Thus, salt marshes are usually small or absent along the coasts of northwest Florida and Alabama; however, there are substantial areas of low and high marsh from Tampa, Florida, north to St. Joseph Bay, Florida. The coast is very gently sloping with many marshes facing directly into the open gulf waters (Carlton, 1977). Extensive salt marshes occur on the flat topography of the lower Mississippi River delta and in eastern Texas. They are backed by large areas of brackish and freshwater marshes. Plantable marsh species are essentially the same throughout the region, although rainfall and temperature vary considerably.

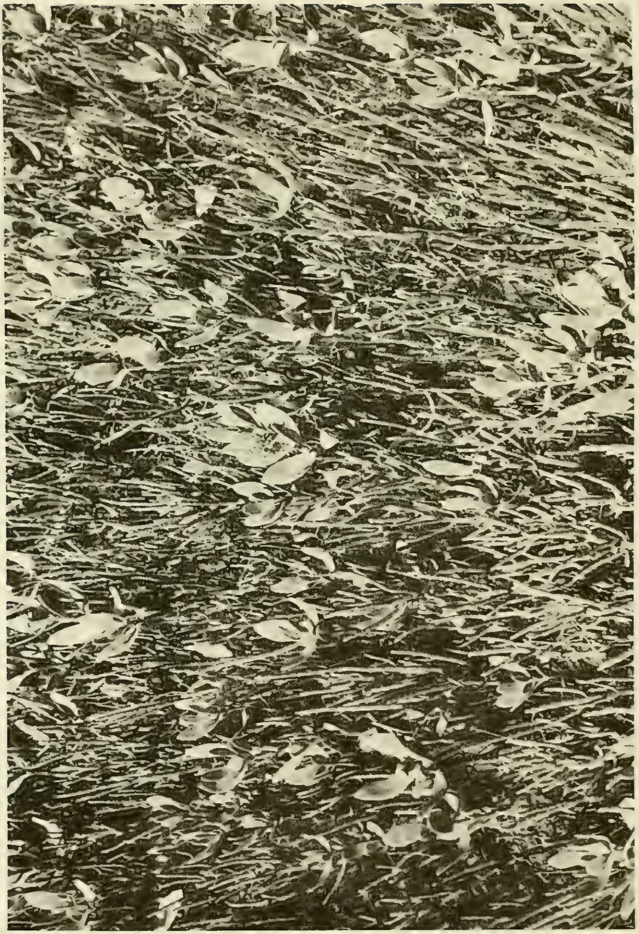

Figure 16. Sea oxeye (broadleaf plant in flower) mixed with pickleweed.

Figure 17. Sea oxeye (left) and marsh elder (right), reprinted from Beal (1977).

(1) Smooth Cordgrass. This is the dominant flowering plant in the regularly flooded intertidal zone wherever salt marsh occurs throughout the gulf coast. There are distinct geographic populations of this grass along the Atlantic and gulf coasts that retain their identity when grown side by side (Seneca, 1974). Plants of the gulf coast have longer and narrower, more upright leaves than those of more northern origin. Other characteristics of smooth cordgrass are discussed in the Atlantic coast, Section IV, 1, a (1).

(2) Saltmeadow Cordgrass. This grass occupies extensive areas of irregularly flooded high marsh on gently sloping topography such as around the mouth of the Mississippi River--6 million hectares in Louisiana alone (Chabreck, 1972). It is often mixed with saltgrass, patches of needle rush, and other high marsh species. Saltmeadow cordgrass also grows at still higher elevations, producing sparse growth on dry sandflats and low dunes. Other characteristics are discussed in the Atlantic coast, Section IV, 1, a (2).

(3) Black Needle Rush. Black needle rush occurs extensively along the gulf coast as high marsh inundated only by wind-driven tides or floodwaters. It also grows in mixture with smooth cordgrass, saltmeadow cordgrass, and saltgrass, often occurring as patches within these stands. Black needle rush frequently occurs in pure stands adjacent to the uplands where there is regular seepage of freshwater. Other characteristics of this plant are discussed in the Atlantic coast, Section IV, 1, a (3).

(4) Saltgrass. This species is widespread in the more saline, high marshes along the gulf coast. It is rarely dominant except in poorly drained patches or in narrow bands. Saltgrass usually occurs in mixture with saltmeadow cordgrass or black needle rush. Other characteristics of this plant are discussed in the Atlantic coast, Section IV, 1, a (5).

(5) Big Cordgrass. This grass grows in low salinity areas, generally above MHW. Along the gulf coast it and common reed frequently form a "cane zone" where there is a strong freshwater influence at the transition to higher ground. Other characteristics are discussed in the Atlantic coast, Section IV, 1, a (6).

(6) Common Reed. This large, coarse grass is widely distributed in brackish to freshwater areas where it grows above MHW. This plant seeds profusely, spreads vegetatively by rhizomes and stolons, and quickly invades disturbed areas. Because common reed can become a nuisance by crowding out more desirable plants, it should be introduced to new areas with extreme caution. Other characteristics are discussed in the Atlantic coast, Section IV, 1, a (7).

(7) Gulf Cordgrass. This is a bunch-type grass somewhat resembling but readily distinguishable from saltmeadow cordgrass by its

bunch habit. Gulf cordgrass replaces saltmeadow cordgrass on heavy-textured soils along the southwest Louisiana and Texas coasts. It is a good stabilizer in the zone above MHW and can be propagated in the same general way as saltmeadow cordgrass (Dodd and Webb, 1975).

(8) Other Plants. There are a number of plants that occur in the salt marshes of this region. Pickleweed (Figs. 16 and 18) is common in the higher parts of the low marsh and often occupies areas of high salt concentration. Sea lavender is present in the higher low marsh. Dropseed, sea oxeye, marsh elder, goldenrod, and sea myrtle (Fig. 19) are common secondary plants of the high marsh. Most of these can be planted but will usually invade planted areas when conditions favor their growth. Saltcedar (*Tamarix gallica*) is an effective stabilizer in the zone above MHW. However, it is propagated by cuttings and requires several years to develop an effective cover. Initial shore stabilization must be by other means. Giant reed (*Arundo donax*) appears to offer some promise in this zone (Webb and Dodd, 1976).

d. North Pacific Coast. The species composition of north Pacific coast marshes is more diverse than that on other coasts of the United States. Also, less discrete elevational "zones" of vegetation are formed in the less saline marshes of the Pacific Northwest, with a gradual change southward to the southern Pacific coast section between Humboldt Bay and San Francisco (MacDonald and Barbour, 1974). Little information is available to guide marsh planting in this region. Successful intertidal plantings have recently been made in the Columbia River estuary under freshwater conditions (Ternyik, 1977). There have been no reports of plantings in brackish or saltwater.

Few of the relatively large variety of plants found in marshes along this coast presently offer promise for planting purposes. More will probably be found useful with further experience. There is no single species such as Pacific cordgrass on the South Pacific and smooth cordgrass on the Atlantic and gulf coasts colonizing and dominating the lowermost, regularly flooded zone of salt marsh vegetation in this region. Also, as pointed out by Chapman (1960), the lower limit of marsh vegetation tends to be farther up in the tidal range from south to north along both the Pacific and the Atlantic coasts. The lower part of the zone, occupied by Pacific cordgrass on the south Pacific coast, probably cannot be planted successfully along the north Pacific coast with the species available. Jefferson (1975) identifies four species, seaside arrowgrass (*Triglochin maritima*), sedge (*Carex lyngbyei*), pickleweed, and tufted hair grass as the most important in trapping sediments along the Oregon coast. Pickleweed, sedge, and tufted hair grass are fairly easy to plant. Seaside arrowgrass has been planted on a very limited scale (John Armstrong, biologist, U.S. Army Engineer District, Seattle, personal communication, 1978). The use of this species for marsh plantings should be investigated as it is a frequent and effective pioneer, particularly on silty substrates.

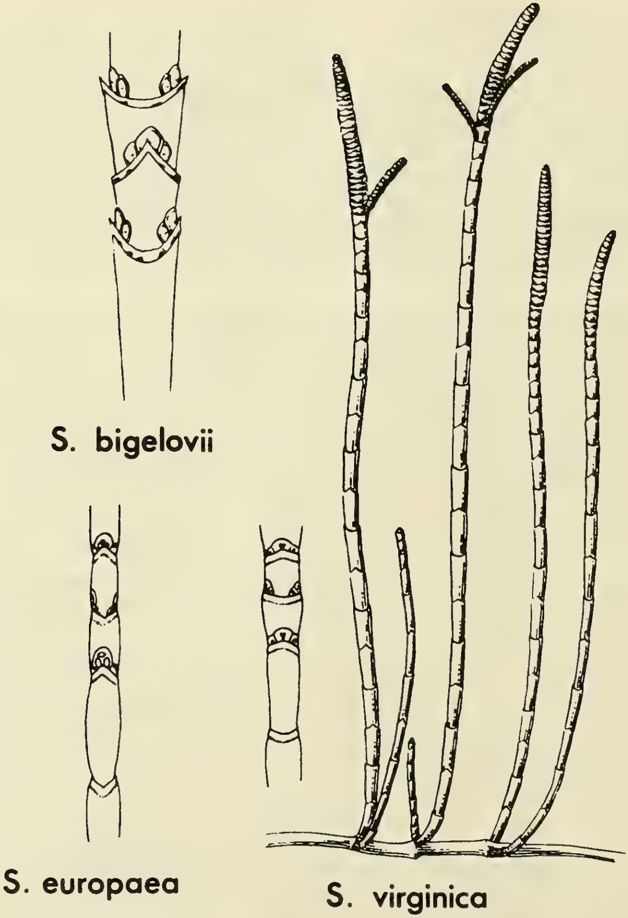

Figure 18. Pickleweed (reprinted from Beal, 1977).

Figure 19. Mixed high marsh--sea myrtle (shrub) growing with black needle rush (background); saltmeadow cordgrass and sea oxeye (foreground).

(1) Pickleweed. This plant is a frequent colonizer of intertidal flats in the more saline waters all along this coast (Figs. 16 and 18). It is a fleshy-stemmed, weedy-type plant that spreads readily vegetatively and by seeds. It invades and covers bare areas rapidly but is unable to persist far down in the tidal range because unlike Pacific cordgrass, farther south, this plant is not equipped to supply oxygen to the roots from the aboveground parts. Pickleweed forms a dense mat above the soil surface, but it is shallow-rooted and is not as effective as a stabilizer as some of the grasses and sedges. Pickleweed is easy to plant, seeds profusely, and often invades disturbed surfaces the first growing season. It is the most logical plant to use at the low elevations down to slightly below mean low high water (MLHW) where salinities occasionally approach sea strength. It should be supplemented with other species at the higher elevations.

(2) Sedge. Sedge marshes usually occur on silty substrates just above colonizing arrowgrass, down to MTL (Fig. 20) (Jefferson, 1973). This plant is less salt-tolerant than pickleweed and is most likely to occur on river delta marshes. It is both taller and a better stabilizer than pickleweed. It is probably the best choice for planting in the intermediate zone where the salinity is not too high. Sedge is plentiful in this region and relatively easy to transplant (Ternyik, 1977).

Figure 20. Mature Lyngby sedge.

(3) Tufted Hair Grass. This is the most prevalent plant in high marsh that is flooded only by the higher high tides (Fig. 21). It grows in elevated tussocks. It is a good stabilizer and sediment accumulator, plentiful, and easy to transplant. Tufted hair grass is the most promising plant for use in the upper third of the tidal range (Ternyik, 1977).

Figure 21. High marsh of maturing tufted hair grass with a scattering of gum plant, jaumea, and seaside plantain.

(4) Saltgrass. This grass is widely distributed along the coast, mainly in the transition zone between low pickleweed and sedge marshes and immature, high marshes. It may serve as a colonizer of bare areas, usually in mixture with other species. Saltgrass seldom occurs alone except in small patches or bands. Experience with this grass elsewhere has shown it to be difficult to plant but quick to naturally invade stands of other planted species. Saltgrass does not appear to be a choice prospect for planting in this region.

(5) Seaside Arrowgrass. This plant is a frequent colonizer at low elevations where it traps sediments and debris and prepares the way for other plants (Fig. 22). Algae and other debris, collected around the stiff flower stalks, often give arrowgrass a distinctive appearance on mud and sand flats. This plant also occurs at higher elevations mixed with other species. It has been transplanted but little is known about its planting requirements.

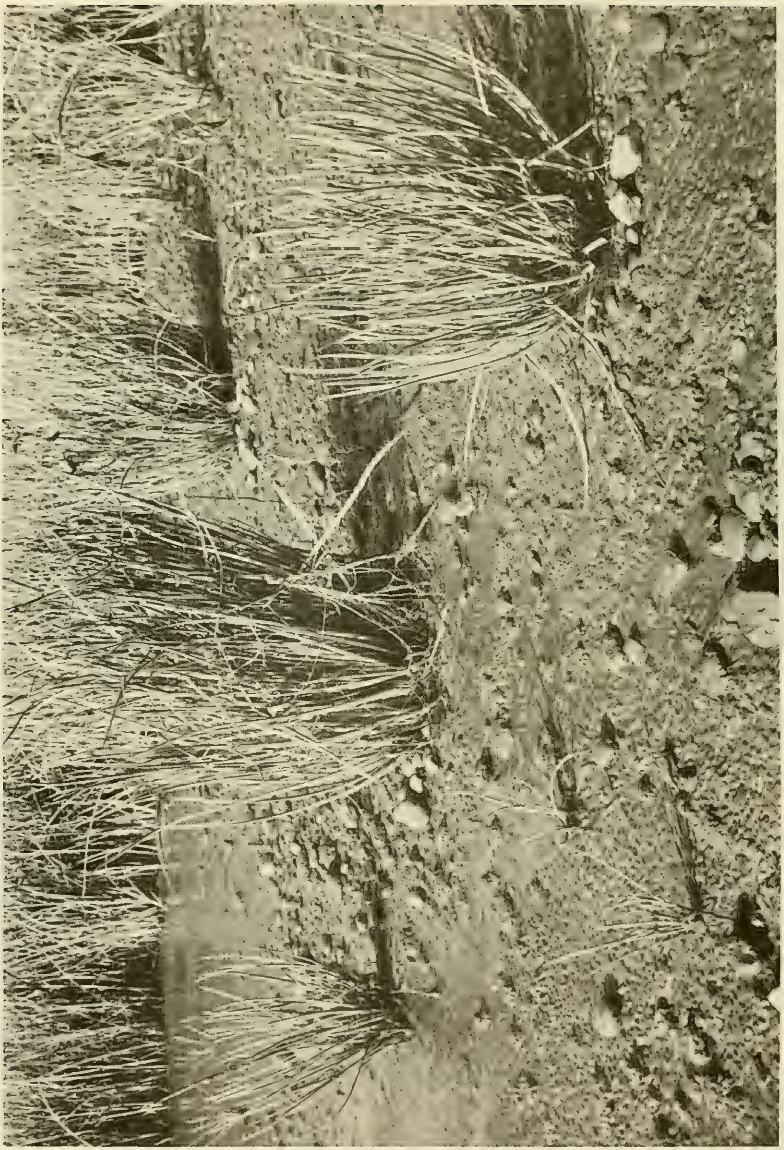

Figure 22. Seaside arrowgrass plants.

(6) Three-Square or Chairmakers Rush (*Scirpus americanus*). This rush often replaces arrowgrass as a pioneer on sandflats where it may occupy substantial areas. It can be transplanted but with more difficulty than such plants as sedge and pickleweed.

(7) Other Plants. There are many species that grow in these marshes mixed with the more common plants and contribute to production and stability. Some of these are Jaumea (*Jaumea carnosa*), sand spurry (*Spergularia spp.*), Pacific silverweed (*Potentilla pacifica*), seaside plantain (*Plantago maritima*), and spike rush (*Eleocharis spp.*). Bulrush (*Scirpus validus*) co-mingles with sedge where there is a strong freshwater influence. All of these plants will invade areas planted to other marsh plants.

(8) Smooth Cordgrass. This species is more vigorous than Pacific cordgrass and would be easier to establish along much of the Pacific coast. It is probably more useful for shoreline stabilization than Pacific cordgrass or sedge. Smooth cordgrass was established accidentally, in conjunction with the introduction of oyster spat, in Willapa Bay, Washington, in 1889 and 1918. The grass has spread extensively into sandflats and has replaced native species (Jefferson, 1975). Smooth cordgrass grows equally well in northern California and would probably grow even better farther south. Consequently, any proposal to introduce this species on the west coast should be carefully considered. Such a step is very likely to be irreversible, for all practical purposes. Therefore, it should not be introduced until all aspects and interests have received full consideration.

e. South Pacific Coast. Most of the salt marshes on this coast are in San Francisco Bay with some northward to Humboldt Bay and smaller areas occurring south to the Mexican border. Most have been substantially altered by man. A variety of plants grow in these marshes with a gradual change in species from north to south. The principal change in species occurs around Point Conception (MacDonald and Barbour, 1974). However, the important aspect from the standpoint of marsh building is that Pacific cordgrass grows throughout the region. It occurs sporadically between Humboldt Bay and San Francisco and regularly within San Francisco Bay south to Mexico. As in other regions, few plantings of the marsh species that grow here have been undertaken.

(1) Pacific Cordgrass. This grass is similar in appearance to the smooth cordgrass of the Atlantic and gulf coasts (Fig. 23) but does not grow quite as tall. It is less vigorous and slower to establish and is unable to withstand as much inundation as smooth cordgrass. Pacific cordgrass is the dominant flowering plant at the lower elevations of intertidal marshes (MTL). It is probably the most useful and effective species for planting.

Pacific cordgrass is adapted to inundation and anaerobic soils through its oxygen transport system (Kasapligil, 1976; Wong, 1976).

Figure 23. Pacific cordgrass in flower.

Hollow air-filled tissue in the stem carries oxygen from the leaves to roots and rhizomes. This mechanism also introduces oxygen into the soil surrounding the root and rhizome system. It tolerates salt by excreting it through salt glands.

Two forms of Pacific cordgrass have been identified in San Francisco: a medium, stout form (0.3 to 1.2 meters high), which grows in the lower zone, and a dwarf (0.2 to 0.3 meter high), which occurs mixed with pickleweed at higher elevations (Kasapligil, 1976). It is not known whether these forms have a genetic basis or are due to environmental features. Short-term field tests (Harvey, 1976) suggest that the two forms react differently to elevation. The dwarf form was able to survive transplanting at a higher elevation than the stout form.

Reproduction in established stands is vegetative through extensive underground stems (rhizomes). Seed production is erratic and usually limited in old, dense stands. It may be substantial in newly established stands or along margins. Seeds are important for spreading the plant into new or freshly disturbed areas (Mason, 1976).

The capacity of Pacific cordgrass to grow lower in the tidal range than any other marsh species makes it especially valuable in marsh building. It provides downslope protection and grows where its detritus is readily transferred to the estuary by tidal action. The association of

ribbed mussels (*Ischadium demissum*) with Pacific cordgrass roots and rhizomes adds substantially to substrate stability. This mussel-cordgrass association may be propagated by planting large plugs (Newcombe, 1978).

Pacific cordgrass grows through most of the upper half of the tidal range. However, only the stunted form appears with pickleweed above MHW. There may be considerable competition from pickleweed in this zone.

(2) Pickleweed. This plant is the principal colonizer from MHW to extreme high tide of recently exposed sites. It is a fleshy-stemmed, weedy-type plant. It spreads by seeds and vegetatively and covers bare areas quickly. Pickleweed is not equipped to supply oxygen to the roots from the above-ground parts. It forms a dense mat above the soil surface but is shallow-rooted; therefore, the plant is not as effective as a stabilizer as Pacific cordgrass. Pickleweed is easy to plant and is the best plant to use upslope of Pacific cordgrass plantings. In less exposed areas, it may not be necessary to plant it (Newcombe and Pride, 1976).

(3) Other Plants. A variety of secondary species occurs in high marshes. Gum plant (*Grindelia sp.*), plantain (*Plantago sp.*), saltbush (*Atriplex sp.*), frankenia (*Frankenia grandifolea*), arrowgrass, sea lavender, Jaumea, seablite, and saltgrass are some of the more common ones. All of these plants contribute to stabilization and productivity. Planting of these is not usually advisable because they will invade stands of more easily planted species.

(4) Smooth Cordgrass. This species is more vigorous than Pacific cordgrass and easier to establish along much of the Pacific coast. It is probably more useful for shoreline stabilization than Pacific cordgrass. Smooth cordgrass was introduced accidentally in Willapa Bay, Washington, in 1889 and 1918 and has spread extensively into flats and has replaced native species (Jefferson, 1975). It appears to be equally well adapted in northern California and will probably grow even better farther south. Consequently, the introduction of this species anywhere along the west coast should be weighed very carefully. Such a step is very likely to be irreversible, for all practical purposes. Therefore, it should not be taken until all aspects and interests have received full consideration.

f. Great Lakes. Marsh planting along the shorelines of the Great Lakes has not been investigated. Hall and Ludwig (1975) surveyed shoreline vegetation in this region and rated the species for their stabilization potential. The following suggestions are based on their findings, plus planting experience and observations made elsewhere.

Shading of marsh and other shoreline plants by tree species requires special attention on some Great Lakes sites because the absence of salt

allows these plants to grow closer to the water. Most marsh species grow best in full sun; their use, in some instances, may require removal of nearby trees.

(1) Common Reed. This is probably the easiest planted of the Great Lakes wetland species. It is a large, coarse grass (1.5 to 4 meters high) which seeds profusely, spreads vegetatively by rhizomes and stolons, and quickly invades disturbed areas. Common reed is an effective stabilizer during the growing season. However, it dies to the ground during the winter and is unable to survive constant inundation. This grass is generally not considered desirable as wildlife food or cover; it can become a nuisance by crowding out more valuable plants.

(2) Other Plants. Spike rush, bulrush, great bulrush (*Scirpus acutus*), scouring rush (*Equisetum spp.*), and bluejoint (*Calamagrostis canadensis*) have promise as stabilizers and should be studied. Experience in field planting spike rush and bulrush species elsewhere has not been encouraging. One cultivated plant, reed canary grass (*Phalaris arundinacea*), may be useful in some instances, and offers the advantage of a commercial seed supply.

Suggestions for the propagation and use of plants that grow immediately above the wetland species are available (Clemens, 1977; Woodhouse, 1978).

2. Cultural Techniques.

The general topic of marsh plant propagation has recently been reviewed (Kadlec and Wentz, 1974; Wentz, Smith, and Kadlec, 1974).

a. Smooth Cordgrass. This plant is propagated by seeds and vegetatively.

(1) Seeds. Seed production is confined largely to new, open stands and along margins; e.g., along tidal creeks. The most vigorous stands usually produce the best seeds but variability is high. Planted areas usually yield heavy seed crops for several years following establishment. Seed heads are frequently damaged by ergot infestation and by flower beetles (family Mordellidae; N. H. Newton, entomologist, North Carolina State University, Raleigh, personal communication, 1976). Flowering time and seed maturity progress from north to south, at least within geographic populations such as along the Virginia-Carolinas coast. For example, there is a spread of about 2 weeks, north to south, in seed maturity along the North Carolina coast with considerable variability within individual stands. Seeds are ready for harvest as early as September in northern latitudes and as late as November in the south Atlantic marshes but maturity varies from year to year.

Harvest (cut and collect seed heads) by wading or from boats. This must be done shortly after maturity when seeds can be readily dislodged from the heads by rubbing as they shatter readily soon after. Heads should be stored moist, but not submerged, at 2° to 3° Celsius, for 2 or 3 weeks to allow "after ripening." They may then be threshed to reduce storage space and to facilitate handling, and stored in water of 20- to 25-parts per thousand salinity (Woodhouse, Seneca, and Broome, 1974) at 2° to 3° Celsius until planting time. Submerged storage is required because drying seeds lose viability rapidly (Mooring, Cooper, and Seneca, 1971) and saline water is preferable, at least in some instances (Woodhouse, Seneca, and Broome, 1974). Low temperatures during storage are essential to retard germination as sprouting of ripe seeds is rapid under higher temperatures following after-ripening. Even under the best storage conditions, large numbers of seed will sprout by the following March or April. These sprouted seeds are still usable for planting but are much more susceptible to damage from handling the unsprouted seeds. Freezing, either wet or dry, is not a satisfactory method of storage (Woodhouse, Seneca, and Broome, 1974). Viability of stored seed is not retained longer than 1 year. Consequently, seed must be harvested each year in September to November for planting the following year.

Smooth cordgrass invades new sites primarily by seeds (Fig. 24); stands can be established by direct seeding on the more protected sites (Woodhouse, Seneca, and Broome, 1972, 1974). When feasible, this will usually be the most economical method. However, vegetative transplants are much more tolerant of waves and currents and should be used on most sites.

Figure 24. Natural stand of smooth cordgrass seedlings.

(2) Transplants. Vegetative transplants may be obtained by thinning natural stands and from plants grown in intertidal nurseries or they may be produced under controlled or semicontrolled conditions by growing seedlings in peat pots.

(a) Field collected plants are satisfactory and often adequate for small-scale plantings. These should come from uncrowded stands. This usually means stands of recent origin. Plants are obtained by loosening individual clumps with a shovel, small back-hoe, or plow, and lifting and separating into individual transplants. Choice transplants consist of large, single stems (culms) with small shoots and short pieces of rhizomes left attached or discarded (Fig. 25). Digging and processing of planting stock from old, dense marshes is difficult and usually yields small, poor quality plants. Where planting stock must be obtained from such stands, it is usually preferable to resort to plugs or cores as these small single stems are not satisfactory as transplants (Woodhouse, Seneca, and Broome, 1974). Heavy harvest of single-culm plants initially appears to be devastating to the stand. However, the effect is very short-lived, particularly in open, vigorous stands on sandy substrates; remaining rhizomes and shoots soon repopulate the area, usually in the same growing season. It is difficult to harvest such sites close enough to prevent overcrowding and the reduction in suitability of the planting stock in succeeding years.

Due to the rapid recovery of vigorous new stands, the harvesting of planting stock from year-old plantings for marsh building is often feasible. Such stands yield excellent quality transplants at low cost with only a slight delay in the process of marsh development.

(b) Field nurseries are relatively easy and economical to establish if suitable sites are available. An ideal site is a bare, smooth intertidal slope of sandy material along a relatively protected shore. The initial stand may be established by seeding or transplanting single stems. Seeding rate should be low and transplants spaced at least 1.5 meters apart. Row planting would facilitate mechanization of harvest operations. Diked pond sites, constructed of dredged materials, make excellent nursery sites if provided with a suitable water supply. Field nurseries are planted in the spring and planting stock is available for harvest the following late winter, spring, and summer. Although this method has not been widely used, it has potential in many areas under periodic dredging operation. Dredged material can be deposited to form an intertidal slope, planted with seeds or transplants in the spring, harvested for planting stock the following winter, spring, and summer, and remain thereafter as an addition to the marshlands of the area. Alternatively, it could be reactivated as a nursery in later years by covering the surface with a thin layer of sandy dredged mate-

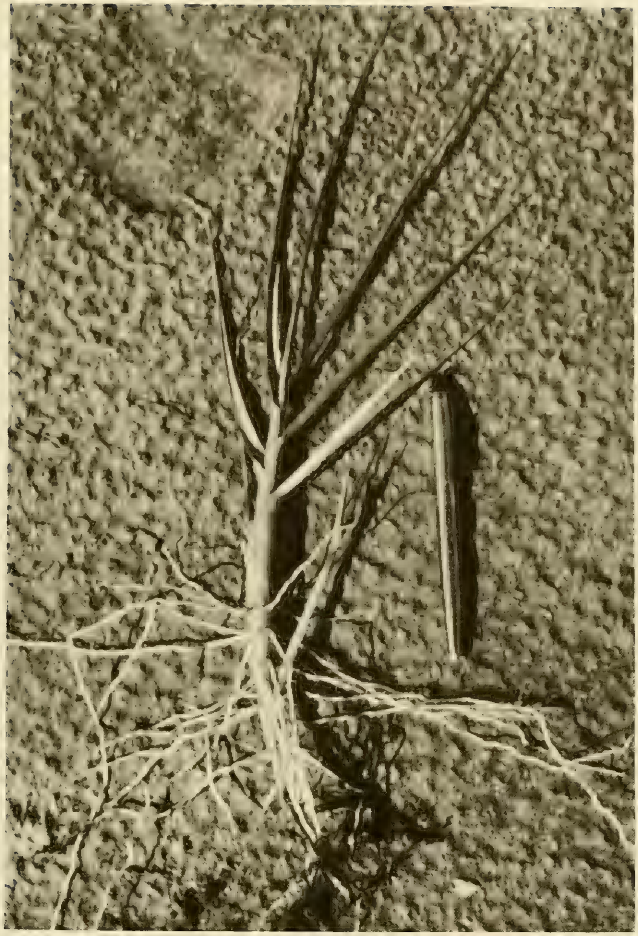

Figure 25. Typical smooth cordgrass transplant or "sprig" from the wild or from an intertidal nursery.

rial. This has not been done on an organized basis but the effect has been observed where dredged material was deposited on established marsh. With proper depth coverage, about 8 to 12 centimeters, vigorous new culms that make good transplants emerge.

(c) Plugs are obtained by excavating cubes or cylinders containing crowns, stems, roots, rhizomes, and soil from a healthy stand of cordgrass growing on a silty or clay substrate. Diameter of plugs must usually be 12 centimeters or more in order to include one or more intact plants. This form of planting stock is considerably more laborious to harvest and transplant but is the only feasible type where plants must be obtained from old, crowded stands on heavy-textured substrates (Terry, Udell, and Zarudsky, 1974; Knutson, 1977a; Banner, 1977).

(d) Seedlings in peat pots are produced in a greenhouse or out-of-doors during mild weather. Seeds are planted directly in sandfilled peat pots or germinated in flats and transplanted to pots later. Garbisch, Woller, and McCallum (1975) grew four to six seedlings in each 5- to 10-centimeter pot. They fertilized with Hoaglands nutrient solution (Hoagland and Arnon, 1938), and adjusted salinity with sodium chloride. They state that salinity conditioning is necessary if seedlings are to be transplanted in salinities above 15 parts per thousand. Garbisch (1977) recommends planting potted seedlings 15 weeks old in sheltered areas and 5- to 7-month-old seedlings on moderately exposed to exposed sites.

Choice of planting stock for any particular site will depend on the quantity required, cost, availability, planting date, planting objective, and exposure. Adequate quantities of quality transplants for small plantings can often be obtained from the wild. When available nearby and readily accessible, these will be the cheapest. However, large quantities of suitable plants are rarely available in any single location, and the accumulation of substantial amounts by gathering small quantities is very time-consuming. Field nurseries or peat pot-grown seedlings are usually the only practical alternatives for larger plantings.

Seedlings growing in peat pots have certain distinct advantages as marsh planting stock, namely:

(1) Availability. This is the only type commercially available at present. It can be produced rather quickly in almost any location and with seedlings ready for transplanting in as little as 15 weeks after seedling emergence.

(2) Reduced Transplanting Shock. Pot-grown transplants suffer less root damage than plants dug from the field and are able to resume growth quicker following transplanting. This extends the planting season by giving the plants a longer period in which to become established.

Peat-pot seedlings also have certain drawbacks. These are:

(1) Cost. No precise cost estimates are available but, based on quoted prices and experience in producing and processing plants, 15-week-old seedlings in 2-centimeter peat pots placed on the planting site will cost at least four or five times as much as planting stock from field nurseries. On small areas planting stock expense may be insignificant but with extensive plantings this factor can become quite large and will often limit project feasibility or project size.

(2) Handling. Peat-pot seedlings are bulky and much heavier than field or nursery transplants, are more difficult to transport, and have more exacting transplanting requirements.

Full cover of smooth cordgrass will develop in late winter or early spring from plants spaced 1 meter or less apart if they become well enough established to stay in place over winter (Fig. 26). The source of plants (direct-seeded, field-grown plant, plug, or peat pot-grown) does not change the outcome. Complete stands develop from widely spaced plants through the proliferation of rhizomes during the fall and winter followed by emergence of large numbers of stems from rhizomes in early spring. The key point is that the plants become established and stay in place over winter to form a complete stand. This can be accomplished on protected sites by direct seeding and, under mild to moderate exposures, with field-grown planting stock, provided planting is early enough for full establishment (spring for seed; spring or early summer for transplants). In general, additional cost and effort associated with peat-pot seedlings would probably be justified only for off-season or late planting (summer or fall) or possibly on the more exposed, high-energy sites.

Rhizomes have been suggested as the logical choice for planting this species. Rhizomes that are unattached to culms are useless as propagules in the intertidal zone (Woodhouse, Seneca, and Broome, 1976).

b. Saltmeadow Cordgrass. This grass is propagated vegetatively and by seeds. It seeds profusely, often invades low, moist sites by seed, and can be direct seeded on protected sites. However, transplanting is preferable on more exposed or steeply sloping areas that may be subject to erosion.

(1) Seeds. Saltmeadow cordgrass is a fairly consistent seed producer. It grows on irregularly flooded and unflooded sites and the

Figure 26. Single-culm transplant, planted 24 March; photo taken 8 July.

seeds do not require moist storage (Webb and Dodd, 1976). Large-scale harvesting and processing of this species could be handled with the same equipment and in a similar manner as many of the cultivated grasses. Small quantities are harvested by hand as with smooth cordgrass. Seed should be stored dry. Storage at low temperature is probably best, although there is no clear-cut evidence to support this.

(2) Transplants. This plant is plentiful in high marshes and on low sandflats along the Atlantic and gulf coasts, but it is difficult to obtain good planting stock from the wild. Stands on moist sites soon become so dense that harvesting is difficult, and the crowded plants do not make vigorous planting stock. Plants growing on dry, infertile sites lose vigor and survive poorly when transplanted. The best transplants are the large culms from rapidly growing, uncrowded young stands; however, obtaining significant quantities of this kind of transplant in most areas will require the establishment of a nursery.

Saltmeadow cordgrass can be grown as readily inland as on the coast. Plant on a weed-free, sandy soil with a moderately good moisture-holding capacity. The seedbed should be well pulverized, and if needed, fumigated with methyl bromide to kill weed seeds. Seed may be used for nursery establishment but transplants are usually more practical. Nursery plantings should be made in late winter or spring. Use one- to three-culm transplants from young, vigorous stands, set 10 to 15 centimeters deep in moist soil, 45 to 60 centimeters apart in rows. Space rows to allow cultivation, usually 75 to 110 centimeters apart. Fertilize at planting. Topdress with nitrogen later if need is indicated by growth and appearance.

It is usually best to harvest nursery-grown stock after one growing season to avoid the development of overcrowded, less desirable plants. Harvest by loosening individual clumps with a shovel, a tree digger, or a similar tool and then lifting. Saltmeadow cordgrass culms are small even under the best growing conditions; clumps should be divided into four- to eight-culm "plants" for transplanting. Plants may be stacked upright in tubs, baskets, or crates for handling and transport, or bundled in the same way as tree seedlings. Care must be taken to avoid drying and heating. Plants may be heeled-in in moist sand for temporary storage.

(3) Peat-Pot Seedlings. Saltmeadow cordgrass may be grown in peat pots in the same general way as described for smooth cordgrass. Seeds are scattered over sandfilled 5- to 10-centimeter peat pots and seedlings are fertilized with Hoaglands solution. In view of the ease of field propagation of this species, there appears to be less justification for this more costly method. However, where salt buildup is likely to interfere with initial establishment, the more intact root systems of the peat pot seedlings should have an advantage. Salt buildup is likely in parts of the saltmeadow cordgrass zone when inundation

by spring or storm tides is followed by periods of low rainfall and warm temperatures. Established plants can tolerate this but fresh transplants may be severely damaged.

c. Pacific Cordgrass. This grass may be propagated vegetatively and by seeds. It has similar but perhaps more exacting propagation requirements than smooth cordgrass.

(1) Seeds. Seed production in Pacific cordgrass is very erratic. Early investigators believed that viable seeds were seldom produced and of minor significance in the spread of this species (Purer, 1942; Hinde, 1954). However, recently substantial seed crops (viability 80 percent) have occurred in the San Francisco Bay area. Seeds from these sites have been harvested and stored, and plants have been produced from them (Mason, 1976). The best seed production was located near bay tributaries. The lower salinities at these sites may be a factor encouraging seed formation although this has not been established. Like smooth cordgrass, Pacific cordgrass seed heads may be attacked by ergot (*Claviceps purpurea*) (Fig. 27) (C. Newcombe, Director, San Francisco Bay Marine Laboratory, personal communication, 1978).

Pacific cordgrass seeds mature in the San Francisco Bay area in October; seed heads begin to shatter shortly thereafter. Harvesting must be timed just before shattering when some seeds are easily dislodged by tapping the heads or stalks. Mature heads may be clipped by hand either from a boat or by wading Seeds should be stored in cold saltwater for about 2 weeks to loosen inflorescences. Seeds may then be threshed by placing heads on a No. 30 screen and subjecting them to a strong spray of water from a hose. Viability of seeds has been maintained over winter by storing in cold (4° Celsius) freshwater or saltwater (11 to 12 parts per thousand). Saltwater is more effective in preventing germination during storage. Satisfactory germination has resulted when seeds were placed in freshwater at the end of the storage period (Mason, 1976). There is some indication that germination of Pacific cordgrass may be more sensitive to salinity than smooth cordgrass. Viability is not maintained by drying or freezing.

Plants have been produced from seeds by direct seeding in sand, sand-silt, or vermiculite mixtures in peat pots or by germinating seeds in petri dishes and transplanting to peat pots (Mason, 1976).

(2) Plants. Four types of Pacific cordgrass transplants have been used successfully in recent trials in the San Francisco Bay area (Knutson, 1975; U. S. Army Engineer District, San Francisco, 1976):

(a) seedlings grown for 4 months in 10-centimeter peat pots;

(b) plugs, prepared by removing 13-centimeter cubes containing crowns, roots, rhizomes, and soil, from a tall, healthy cordgrass marsh;

Photo courtesy of Paul Knutson

Figure 27. Ergot on Pacific cordgrass.

(c) robust "cuttings" prepared by transplanting small shoots from tall, healthy plants into 10-centimeter peat pots in September for field planting the following spring;

(d) dwarf "cuttings" prepared in the same way as above with shoots from dwarf cordgrass. All peat pots were cultured over winter in tanks inundated 8 hours daily with San Francisco Bay water at salinities of 10 to 15 parts per thousand.

Each of the four types were about equally effective as transplants. Survival was better for the dwarf cuttings than for the robust, and first-year growth of the peat-pot seedlings was below that of the plugs and cuttings. However, growth evened out the second year and the predicted time for the development of a mature stand (3 years) was the same for all four types and for direct seeding.

Transplanting of freshly dug Pacific cordgrass plants or "sprigs" from natural marshes or intertidal nurseries, as used with smooth cordgrass (Woodhouse, Seneca, and Broome, 1972), was quite successful in a 1976 test (Morris and Newcombe, 1978). Survival and first-year growth was substantially better than with the four transplant types used in the earlier trial. However, this trial did not provide a valid comparison of transplant types because the 1976 plantings were located in an abandoned saltpond that had been breached and filled with dredged material. This provided a somewhat more protected site than that used in the first test. Also, most of the area was in the upper end of the elevation range for Pacific cordgrass. Even so, these results are encouraging for the use of sprigs. These are much cheaper than the other transplant types and may be preferable from the standpoint of survival and early growth.

d. Black Needle Rush. This plant is propagated vegetatively and by seeds. Transplant success has been erratic. Plants from young, uncrowded stands are definitely preferable to older plants. Seeds may germinate as soon as shed. They require light and constant wetness and they germinate best in freshwater; prolonged exposure to salinities above 1 percent are detrimental. Black needle rush seeds are more difficult to harvest than seeds of the cordgrasses. Seedlings have been produced in peat pots (Garbisch, Woller, and McCallum, 1975) which is probably the most reliable method. However, in light of the difficulties encountered in direct establishment of this species and the propensity it has for invading stands of other marsh plants after stabilization, direct planting of black needle rush is seldom justified. Usually, it is much easier to stabilize the area with smooth cordgrass or saltmeadow cordgrass and allow black needle rush to invade naturally where it is best adapted. If large grass plantings are isolated from natural stands, it may be advisable to include 1 to 5 percent black needle rush in the initial planting to ensure the presence of a seed supply.

e. Sedge (*Carex lyngbei*). This plant spreads vegetatively and by seeds. Planting has been limited to transplants gathered from the wild. This appears to be both satisfactory and practical for small to moderate plantings. Sedge is plentiful throughout most of the Pacific Northwest and it is easy to dig and transplant (Ternyik, 1977). Plants should be from young stands that are 2 years old or less and probably should consist of three or more stems. Preliminary tests using plugs were not encouraging. Good quality planting stock may be readily produced from older stands by covering them with 10 to 15 centimeters of dredged material the year before the plants are to be used. As a large amount of this species is present in the region, this may often be more feasible than planting nurseries.

f. Tufted Hair Grass. This plant spreads vegetatively and by seeds but plantings have been done using material gathered from the wild (Ternyik, 1977). As tufted hair grass is plentiful throughout the region and easy to dig, wild plants will probably be an adequate source for small projects. It should be relatively easy to propagate under nursery conditions because it grows readily above the normal tidal range. A nursery procedure similar to that described for saltmeadow cordgrass is suggested. Sprigs should probably be multistemmed. Direct seeding has not been tried.

g. Arrowgrass. Spread of this plant is vegetative and by seeds. Limited planting has been with multistemmed sprigs or plugs. It is fairly plentiful in the Pacific Northwest.

h. Gulf Cordgrass. This plant spreads vegetatively and by seeds. It has only been planted vegetatively using sprigs gathered from the wild (Dodd and Webb, 1975; Webb and Dodd, 1976). It is plentiful in the gulf coast region of Texas on moist upland sites where clay occurs close to the surface. It would probably be easy to propagate under nursery conditions, following the same procedure as for saltmeadow cordgrass. Selection of a sandy surface soil, underlain by clay, should result in vigorous growth and facilitate harvesting of planting stock.

i. Big Cordgrass. This plant spreads vegetatively and by seeds. Plants have been grown from seeds in peat pots (Garbisch, 1977). Planting has also been done, using transplants collected from the wild. However, this plant does not transplant as readily as smooth and saltmeadow cordgrasses and it is essential to use material from young, uncrowded stands for transplanting. These stands are usually scarce and difficult to find. In view of the specific elevation and flooding requirements of big cordgrass, suitable nursery sites will probably be difficult to find and develop. Consequently, planting stock production by seeding in peat pots is probably the most feasible method.

j. Saltgrass. This plant spreads vegetatively and by seeds. Transplanting success using sprigs has been poor. Survival has been low and initial growth slow. Plugs may be more effective. Somewhat better

results have been obtained with peat pot-grown seedlings (Garbisch, Woller and McCallum, 1975). Because saltgrass readily invades established stands of other marsh species, artificial propagation of this plant is seldom worthwhile.

k. Mangroves. Mangroves invade new areas by seeds. However, like most tree species, they invade raw, unstabilized areas with difficulty (Lewis and Dunstan, 1975; Teas, Jergens, and Kimball, 1975; Banner, 1977). Consequently, transplants seem to hold more promise.

Red, white, and black mangrove seedlings are readily grown in pots (Savage, 1972). Germinated seedlings may be gathered in large numbers from drift lines for potting during the winter and early spring (H. Teas, botanist, University of Miami, Coral Gables, Florida, personal communication, 1976). Growth requirements for mangrove plants in containers appear to be similar to those of other marsh species. Larger containers may be required. Moisture supply must be maintained at an adequate level; however, flooding is not essential in the production of the Florida mangrove species. Best survival has been with large plants (saplings, 0.5 to 1.5 meters in height, 4 to 5 years old). These can be transplanted with a high degree of success if root-balled and pruned when dug from the field (Darovec, et al., 1975; Pulver, 1976). Root-ball (roots and soil surrounding tree) diameter should be at least one-half the height of the tree before pruning and about 20 to 25 centimeters deep. Similar plants, container grown, should plant equally well. The supply of such plants available from the wild is very limited and extensive plantings will require nursery stock grown from seedlings or from rooted cuttings. Air-layering has promise in the production of mangrove planting stock (Carlton and Moffler, 1978).

l. Pickleweed. This plant spreads vegetatively and by seeds. Planting has been with sprigs gathered from the wild (Newcombe and Pride, 1976). It is plentiful all along the Pacific coast and often invades newly exposed sites the first year. Consequently, there is little need for propagation.

m. Other Plants. A number of other plants could be planted for special purposes. Common reed is abundant locally along the Atlantic and gulf coasts and ample planting material, sprigs, rhizomes, and stolons may be obtained from the wild. Sea oxeye, marsh elder, and several of the other minor marsh species have been sprigged successfully in experimental plantings. Propagation would be similar to the major species.

3. Planting Techniques.

a. Site Preparation. Disturbance and manipulation of surfaces for planting should be limited to the need for suitable slopes. Grading may be required to eliminate pockets of poor drainage. Sloping or filling may be necessary on eroding shorelines to provide a plantable

slope. Cultivation beyond that required to facilitate grading will usually only increase erodibility and should be avoided.

b. Fertilization. Nutrient supplies in regularly flooded salt marshes are usually adequate, particularly in established marshes in sediment-rich estuaries. Large quantities of nutrients are stored in fine-grained sediments, and this supply is regularly augmented by fresh deposits. However, fertilizers can be a useful tool in establishing new stands of marsh under certain circumstances. Freshly deposited or exposed sandy substrates are usually deficient in nutrients, particularly nitrogen and phosphorus. The addition of these nutrients will accelerate growth thereby shortening the time that establishing plants are most vulnerable to waves and currents. (Woodhouse, Seneca, and Broome, 1972, 1974, 1976; Garbisch, Woller, and McCallum, 1975).

Fertilizer response is usually, but not always, confined to sandy substrates. Deficiencies acute enough to severely hamper plant establishment have been found on heavy-textured soils (Broome, in preparation, 1979) (Fig. 28). So far these appear to be confined to eroding shorelines but this problem could be more widespread. Nutrient supply should be examined wherever unusual difficulty in marsh plant establishment occurs, regardless of substrate texture or origin; field tests are the only reliable indicators of fertilizer response under marsh conditions. Chemical tests and their interpretation are considerably less advanced for marsh soils than for upland soils.

Demonstrated fertilizer response of salt marsh species has been to nitrogen and phosphorus. Benefits from additional potassium or micronutrients are unlikely under salt or brackish water conditions.

Form of nitrogen is important. Nitrate is subject to rapid denitrification under anaerobic conditions (Patrick and Mahapatra, 1968). Ammonia is utilized more efficiently by smooth cordgrass than the nitrate form, just the reverse from most upland plants (Gosselink, 1970; Woodhouse, Seneca, and Broome, 1976; Mendelssohn, 1978). This is probably true for other marsh species because ammonia is the normal form of nitrogen existing under anaerobic conditions. Results with urea have been similar to those with nitrate (Broome, in preparation, 1979).

Conventional materials such as ammonium sulfate and triple superphosphate are usually the most economical fertilizers for marsh plantings. Slow-release fertilizer such as Osmocote and magnesium-ammonium-phosphate may be very effective on marsh plantings (Garbisch, 1977) but there is no indication that these materials are better than conventional forms, properly used (Broome, in preparation, 1979). For example, 50 kilograms per hectare each of N, P_2O_5, and K_2O from soluble sources placed in the planting hole was as effective as 100 kilograms of nitrogen plus phosphate and potash from Osmocote applied in the furrow (Fig. 29). Slow-release materials may permit the use of lower

Figure 28. Response of smooth cordgrass to fertilizer--no fertilizer (left), 100 kilograms of nitrogen (center), 200 kilograms of nitrogen, and 50 kilograms of phosphate per hectare (right).

Figure 29. Fertilizer placement on smooth cordgrass--50 kilograms of N from Osmocote, surface applied (left), 100 kilograms of N from Osmocote, in the furrow (center), 50 kilograms per hectare each of N, P, and K in the planting hole (right).

rates, particularly of nitrogen, to obtain the same result and are more convenient in that they require fewer applications. However, they are far more expensive and where cost is a factor, as on large plantings, only the conventional forms appear to be practical.

Placement of soluble fertilizers appears to be of little consequence on sandy substrates. Ammonium sulfate and triple superphosphate applied on the bare soil surface at low tide can be very effective and remain in place suprisingly well with little evidence of lateral movement (Woodhouse, Seneca, and Broome, 1974). However, surface application may be very ineffective on compact soils. In the comparison shown in Fig. 29 both the soluble and slow-release materials applied subsurface produced a fivefold to tenfold increase in growth over the surface-applied slow release. Soluble as well as slow-release fertilizer materials should be applied in the planting holes or furrows and covered prior to reflooding on heavy-textured soils.

Split applications of nitrogen (ammonia forms) are likely to result in more efficient utilization than large single applications on sandy soils. Three applications of 30 to 50 kilograms of nitrogen (N) per hectare and one application of 30 to 50 kilograms of phosphate (P_2O_5) per hectare may be warranted during the first growing season on sands. The phosphate and the first nitrogen application should be made 2 to 4 weeks after planting or as soon as new growth appears. The other nitrogen applications should follow at 6-week intervals.

A possible acceleration of eutrophication by the addition of fertilizers to estuaries should be considered. Although there are no data bearing directly on this problem, the judicial use of fertilizers in marsh establishment is unlikely to contribute significantly to the pollution load of most estuaries for the following reasons:

(a) Applied nitrogen utilization by marsh plantings can be quite efficient. Apparent recovery in aboveground growth in the year of application has been as high as 50 percent, comparable to that of upland crops (Woodhouse, Seneca, and Broome, 1976).

(b) The amount of nitrogen applied in a planting, encompassing only a small part of an estuary, is usually insignificant in comparison with the nitrogen regularly entering estuaries from other sources (agricultural, municipal, and industrial).

(c) Little fertilizer phosphorus is likely to leave a planted area because of the affinity of marsh sediments for this nutrient.

(d) Fertilization will normally be a one-season event, applied only in the year of establishment. The resulting marsh will be capable of immobilizing much larger quantities of pollutants in succeeding years.

(e) Slow-release material will probably contribute even less to the waters of the estuary.

c. Erosion and Deposition. Sediment movement may bury or dislodge young plants and seriously interfere with the establishment of plantings. This is particularly critical on direct seedings but is also often important on vegetative plantings. There are many exposed sites where marsh vegetation might do well once established. However, without some kind of temporary protection, new plantings may have little chance of establishing.

The solution of this type of problem will vary widely. On large deposits of sand lying in and above the intertidal zone, wind transport can be substantial. In such cases, properly placed sand fences may be used to protect plantings and prevent failure (Woodhouse, Seneca, and Broome, 1974) (Fig. 30). Movement by waves or currents is a frequent problem that is usually much more difficult to combat. Remedies that have been tried with varying success are breakwaters of scrap tires, baled hay and scrap tires (Webb and Dodd, 1976, 1978), sandbags (Webb, et al., 1978), sandbags and scrap tires (S. W. Broome, soil scientist, North Carolina State University, Raleigh, personal communication, 1978), fiberglass (Garbisch, Woller, and McCallum, 1975), and cloth or net mulch (Morris and Newcombe, 1978). Unfortunately, temporary protection for a planting may cost more than the planting itself and may not be effective. There is a great need for imaginative development of temporary, inexpensive protective devices for this purpose.

Figure 30. Sand fence protecting marsh seeding (right) from sandy dredge material (left), 4 months after fencing.

d. Species.

(1) Smooth Cordgrass. This is the most widely planted marsh plant along the Atlantic and gulf coasts. It is relatively easy to plant, and is capable of growing on a variety of substrates, from coarse sands to clays to peat.

(a) Planting Method. Seeds should be broadcast at low tide and covered 1 to 3 centimeters deep by tillage. It is usually advisable to till both before and after broadcasting to ensure more uniform coverage. Wet seeds will separate satisfactorily for broadcasting if mixed with dry sand. Field-grown transplants may be hand-planted by inserting them 10 to 15 centimeters deep in holes opened by a dibble or shovel (Fig. 31) or by machine in furrows (Fig. 32), taking care to firm the soil around them immediately to prevent "float out." Planting is generally feasible only during low water when the substrate surface is exposed. Plugs are planted in the same general way, usually by hand in holes large enough to accommodate them. Plugs should be set slightly below the substrate surface and soil firmed tightly around them. Peat-pot seedlings are planted in the same manner as plugs. Transplanting machines may be adapted to handle them.

(b) Elevation. Seeding is usually feasible only in the upper 20 to 30 percent of the tidal range. Stands established by seeding will spread downslope by rhizome extension to the lower limit for the site. Smooth cordgrass can be established by vegetative transplants from about MHW to MTL in areas with wide tidal ranges and regular tides. Where tidal ranges are low and tides frequently affected by wind setup, planting may be feasible down to mean low water (MLW). Observations of natural marsh in the vicinity will usually provide reliable estimates of plantable elevations.

(c) Density. The optimum density for seeding appears to be around 100 viable seeds per square meter but adequate stands have been obtained under favorable conditions with less than half this rate. Vegetative transplants (field-grown, plug, or peat-pot) set on 1-meter centers will, under average conditions, provide complete cover by early spring of the second growing season. Denser spacing (0.5 and sometimes 0.3 meter) may be warranted on exposed sites or where early stabilization is required. Planting costs are in almost direct proportion to the number of plants planted. A 0.5-meter planting will require four times as many plants as a 1.0-meter spacing and cost about four times as much. Differences between them will often not be distinguishable after the first growing season.

(d) Planting Date. Smooth cordgrass seeds germinate in nature rather early (late February or March, along the coast of the Carolinas; December and January in Florida). However, direct seeding has generally been more successful where seeds were held in cold storage and seeded in April or early May after storm hazards have diminished.

Figure 31. Hand-planting smooth cordgrass.

Figure 32. Machine-planting smooth cordgrass with single-row planter.

Seedings made as late as June have established successfully. Smooth cordgrass vegetative material can be planted year round but not with equal success. Early spring planting avoids the winter storms and provides a long growing season for establishment. Late spring and early summer planting may lessen the storm hazard but leave too little time for full establishment, particularly in the more northern latitudes. March, April, and early May probably represent the optimum planting season along the mid-Atlantic coast with the season starting somewhat later and becoming shorter northward. The practical planting season starts as early as February and extends much longer in the more southern extremes. Mid-summer plantings have been successful on the gulf coast.

(e) Management. Rhizomes and culms of smooth cordgrass are consumed by certain wildfowl, particularly Canada and Snow Geese, and new plantings may be severely decimated near wintering grounds of these species. Depredations have been controlled by netting placed on the surface, and by barriers erected on the open-water side of plantings (Garbisch, 1977). Other animals such as crabs, muskrats, nutria, rabbits, and cattle may also cause serious damage. Insects often affect seed production.

Litter and debris deposited particularly by storm and spring tides can be heavy enough to smother out stands. The extent of this problem varies widely from place to place. Plantings should be inspected during the first year, and periodic removal practiced when necessary.

Plantings in nutrient poor situations (very sandy sediments, low sediment and nutrient content of tidal waters, or in some cases, heavy-textured substrates) may fail for lack of nutrients. Nitrogen is usually the first limiting nutrient followed by phosphorus. Where nutrient deficiencies are expected on sandy soils, try 50 kilograms per hectare of nitrogen (N) from ammonium sulfate and 50 kilograms per hectare of phosphate (P_2O_5) from a soluble source such as triple superphosphate, applied a few weeks after planting or as soon as new growth appears. A second and third application of nitrogen at 6-week intervals will be beneficial in severely deficient situations. Fertilizer application to heavy-textured soils should be in the planting hole or furrow. The number of applications required by some plantings may be reduced through the use of slow-release materials but this will greatly increase fertilizer cost. Normally, fertilizers are used only during the first growing season to speed plant establishment. They may be helpful in stimulating growth to increase tolerance to wave stress by established stands.

(2) Saltmeadow Cordgrass. This grass is the most common plant in the elevation zone immediately above smooth cordgrass along the Atlantic and gulf coasts except in heavier soils along the Louisiana and Texas coasts where it is replaced by gulf cordgrass. It is relatively easy to propagate and plant.

(a) Planting Methods. Field-grown plants may be planted by hand by inserting them 15 to 20 centimeters deep in holes opened with a dibble or shovel or by machine in furrows. Soil should be firmed around them to minimize blowouts and washouts. Peat-pot plants are planted in the same way with holes or furrows enlarged to accommodate their larger diameter. Some machines can be modified to handle them. Soil should always be moist at planting.

(b) Elevation. Saltmeadow cordgrass exhibits an unusual reaction to elevation in that it grows lower in the tidal range from south to north. It is found well above MHW in Georgia, in the upper 10 percent of the mean tidal range in Maine, and in an intermediate position on the Delaware coast (Reimold and Linthurst, 1977). Planting elevation for this species should either coincide with that of natural stands in the vicinity, or it should overlap a part of the planting zones for other species planted above and below it.

(c) Density. Spacing of saltmeadow cordgrass plants has generally been about 1 meter on centers. With good survival, plants at this density cover fairly rapidly. Closer spacing (down to 0.5 meter) is probably warranted where early stabilization is required or where poor survival is expected.

(d) Planting Date. This plant has a rather wide tolerance to time of planting, from late winter to early summer; Gallagher, Plumley, and Wolf (1977) suggest fall planting but this has not been tested. Late spring is probably the preferred time in most cases. However, where salt buildup is likely, earlier planting is essential. Soil moisture content during and following planting is probably more important for this species than planting date.

(e) Management. Saltmeadow cordgrass is very responsive to fertilizers under nutrient-poor conditions. Response usually occurs on sandy or peaty substrates but occasionally extends to silts and clays. Under these conditions, fertilizer can be a useful and relatively inexpensive tool in promoting rapid establishment and resistance to wave stress. Where nutrient deficiency is expected, apply 30 to 50 kilograms of nitrogen (N) and phosphate (P_2O_5) per hectare from soluble sources 2 to 4 weeks after planting or as soon as new growth appears. Follow at about 6-week intervals with a second and third application of nitrogen. Plantings may be smothered by drifted debris in some locations following unusually high tides. Saltmeadow cordgrass plantings may be damaged by animals and insects but the species appears less susceptible to this problem than smooth cordgrass.

(3) Pacific Cordgrass. This species is the dominant flowering plant at the lower elevations of salt marshes along the Pacific Coast from just north of San Francisco southward into Mexico. It has been planted successfully. Pacific cordgrass appears to be similar to smooth

cordgrass in propagation requirements but experience is much more limited. Consequently, suggested procedures are preliminary and subject to revision.

(a) Planting Methods. Planting of Pacific cordgrass to date has all been on soft, fine-textured substrates. Plants were inserted by hand in hand- or dibble-opened holes. Limited attempts at mechanization were not encouraging. However, if larger scale plantings are made, methods developed for smooth cordgrass could, with minor adaptations, be used with this plant.

(b) Elevation. Pacific cordgrass is adapted to about the upper half of the tidal range but appears in a stunted form, mixed with pickleweed between MHW and mean higher high water (MHHW). Where possible, natural stands in the vicinity should be used as guides to determine planting elevations.

(c) Density. Tests indicate that 0.5- to 1.0-meter spacings of vegetative materials are satisfactory with the closer spacing warranted only where early stabilization is required (Morris and Newcombe, 1978). Differences between a 0.5- and 1.0 meter spacing disappeared by the end of the second growing season. The required density for direct seeding is probably on the same order as for smooth cordgrass, 50 to 100 viable seeds per square meter.

(d) Planting Date. Morris and Newcombe (1978) transplanted Pacific cordgrass at monthly intervals and concluded that survival was best for plantings made in the July to December period; growth was best April to August. Early spring planting (April) is preferred for stabilization, but the entire period (April through December) may be used for marsh establishment.

(e) Management. Limited fertilizer tests with Pacific cordgrass on fine-textured substrates have been unproductive. However, this plant will probably respond similarly to other salt marsh species, such as smooth and saltmeadow cordgrasses under nutrient-poor conditions. Fertilizers should be tried where deficiencies are suspected. Debris deposited by high tides is a definite hazard to Pacific cordgrass in some locations. Regular inspection and removal should be practiced.

(4) Black Needle Rush. This plant is an important and extensively occurring high marsh species along the Atlantic and gulf coasts. It would be more practical, in most cases, to plant smooth and saltmeadow cordgrasses and rely on natural invasion for the introduction of needle rush.

(a) Planting Methods, Density, Date, and Management. These are similar to those described for smooth and saltmeadow cordgrasses.

(b) Elevation. Needle rush grows over a range of elevations upward from about MHW which is probably controlled to some degree by salinity and nature of tidal regime. There may also be different populations of this plant that have developed in different regions similar to those of smooth cordgrass (Seneca, 1974).

(5) Sedge. This plant is a major component of salt, brackish, and fresh water marshes in the Pacific Northwest. It has been planted successfully and appears to be one of the best prospects for marsh planting in this region.

(a) Planting Method. Although sedge has been planted only by hand it would work well in present planting machines.

(b) Elevation. This species can be planted from about MTL or a little below to above MHHW but grows best in midrange. Planting elevation should be partly determined by other species to be planted.

(c) Density. Experience is inadequate to establish planting density.. Based on general growth habit, a spacing of 0.5 to 1.0 meter on centers appears practical for this species.

(d) Planting Date. April through June appears to be the preferred time for transplanting.

(e) Management. Sedge was reported as very responsive to fertilization on a sandy substrate in the lower Columbia River, with little or no growth on unfertilized plots (Ternyik, 1977). This plant will probably respond to nitrogen and phosphorus under deficient conditions in about the same way as smooth cordgrass. Tidal debris is definitely a problem on many sites in this region, and care should be taken to prevent smothering of new plantings where heavy deposition of wood or litter occurs.

(6) Tufted Hair Grass. Experience with planting this species is limited, but it has been planted successfully. It is easy to transplant and quick to establish. It is widely distributed in the Pacific Northwest and available in large quantities in the wild (Ternyik, 1977).

(a) Planting Method. Tufted hair grass has only been planted by hand, 10 to 12 centimeters deep. Some planting machines could be adapted to handle it.

(b) Elevation. Natural range is from about MLHW upward, but it can be planted successfully down to about MTL. When used with sedge, the two species probably should overlap around or just above MHHW.

(c) Density. Plantings spaced from 0.5 to 1.0 meter on centers are suggested.

(d) Planting Date. Based on behavior of similar species, April or May appears to be the best time to plant this grass.

(e) Management. There was some indication of fertilizer response on sandy substrate in the lower Columbia River, but it was not as striking as on sedge (Ternyik, 1977). Fertilizers (nitrogen and phosphorus) should be tried on this species where nutrient deficiencies are suspected. Debris deposited by high tides is definitely a hazard to plantings of this grass on many sites in the Pacific Northwest. Regular inspection and removal should be practiced where wood or litter deposition is heavy. Tufted hair grass is grazed by wildfowl which could interfere with establishment in concentration areas.

(7) Arrowgrass. Based on very limited experience, planting of this plant should follow similar procedures to those for sedge.

(8) Big Cordgrass. This is a common salt and brackish water marsh plant growing at and just above mean high water along the Atlantic and gulf coasts. It is more difficult to plant than either smooth or saltmeadow cordgrass.

(a) Planting Method. Planting of sprigs or peat-pot seedlings should be in the same manner as with the corresponding materials of saltmeadow cordgrass.

(b) Planting Density, Date, and Management. Planting experience with big cordgrass is inadequate to warrant specific suggestions on these points. It is assumed they would be similar to saltmeadow cordgrass.

(9) Saltgrass. It is best to use peat-pot seedlings when planting this species. These should be planted in the spring, set about 3 centimeters below the surface on elevations from about MHW (east coast) or MLHW (west coast), upward in areas subjected to relatively high salt concentrations. No special management requirements for this grass are known.

(10) Common Reed. This is a vigorous, weedy plant that is widely distributed and easy to plant from slightly below MHW upward.

(a) Planting Method. Hand or machine plant, upright, leaving a few centimeters exposed. Plant only when soil is moist.

(b) Planting Density, Date, and Management. Space sprigs 0.5 to 1.0 meter on centers. Spring is probably preferred planting time. This plant requires little management.

(11) Mangroves. Mangrove planting in Florida has been recently reviewed (Teas, 1977). These are tree species and their planting requirements are similar to those of most terrestial tree species. It is usually best to stabilize bare sites with salt marsh plants before attempting to establish mangroves. The southern limit for the use of smooth cordgrass for this purpose is not known. It probably falls just north of Miami on the Atlantic coast and near Cape Romano on the gulf coast.

(a) Planting Method. Plants should be set in holes large enough to accommodate the root mass, at about the same level in the ground as they were growing with the edges of the hole filled and firmed. This can be done best at low tide. The root ball should be kept intact and care taken not to cover pneumataphores or prop roots.

Watering is advisable at higher elevations where daily flooding does not occur. Pruning definitely improves survival and early growth. Black and white mangroves should have top and side branches pruned to about two-thirds of their original length. Pruning of red mangroves must be selective; lateral buds may not grow on branches pruned back to a diameter greater than 2.5 centimeters (Pulver, 1976).

(b) Elevation. Established red mangroves tolerate continuous water coverage of the substrate surface 0.5 meter deep to occasional flooding a few centimeters deep. The black mangrove grows slightly higher, under a few centimeters of standing water to barely flooded by spring or storm tides. The white mangrove will grow with the other two at about all elevations (Davis, 1940). Successful plantings of all three species have generally been from MTL, upward. Propagules and young plants cannot tolerate continuous flooding (Teas, 1977). It may be possible to succeed at lower elevations by using older plants.

(c) Density. It may be feasible to plant seedlings as close as 0.5 meter on centers and permit natural thinning to determine the final stand. With the more expensive saplings, a 2- to 3-meter spacing is suggested.

(d) Planting Date. The optimum planting season of young seedlings, dug from the wild, is in late February and March. Planting of larger plants can probably be done successfully throughout the year if done with care.

(e) Management. There are no data to support the use of fertilizers on mangrove plantings. These species respond to fertilizer in nurseries (Teas, 1977) and will probably respond to the addition of nitrogen and phosphorus in the field on some sites. The cost of slow-release materials such as Osmocote or magnesium-ammonium-phosphate, applied in the planting hole, would be warranted if needed, for the larger transplants. Fertilization should be tried wherever nutrient limitations are suspected. Smothering by drifting debris is a

problem on some sites, particularly with small plants. Inspection and removal should be practiced during the period of establishment. Pruning of established plants may be continued where mangroves play an ornamental role. The black and white species will tolerate severe selective pruning; the red should be pruned with care, cutting only branches smaller than 2.5 centimeters.

4. Marsh Maturation.

The first stage in marsh creation, the development of a full cover of marsh plants with a standing crop approaching that of a natural marsh, may be completed rather rapidly. Smooth cordgrass plantings on the south Atlantic and gulf coasts often reach this stage by the end of the second growing season, 15 to 20 months after planting (Figs. 33, 34, and 35). Pacific cordgrass apparently takes longer, perhaps an additional year. However, the time required for such stands to become fully functioning marshes will not be known until new stands, under a variety of conditions, can be followed through to maturity.

Figure 33. Smooth cordgrass 8 weeks after planting.

Figure 34. Smooth cordgrass 5 weeks later. Note rapid expansion during this period.

Figure 35. Beginning of second growing season 12 months after planting. Note disappearance of rows.

A few workers have examined the early stages of maturation in planted stands (Garbisch, Woller, and McCallum, 1975; Cammen, 1976; Cammen, Seneca, and Copeland, 1976; Newcombe and Pride, 1976; Morris and Newcombe, 1978). This is not a rapid process and it is one that may vary a great deal with such things as location, size of planting, substrate, salinity, and tidal regime.

In any event, once a stand is established, it seems highly unlikely that mode of initiation of the marsh will affect the rate of marsh development.

5. Cost.

The labor required to acquire or produce propagules and to plant is the principal cost of marsh building after site preparation. Labor demands vary widely with species, availability of plants and seeds, type of propagule, accessibility of the site, substrate type, size of operation, and degree of mechanization used.

The most extensive experience is with sprigs (intact single-stem plants) of smooth cordgrass. Estimates for digging, processing, and planting range from about 75 hills per man-hour for a manual operation (Dodd and Webb, 1975) to about 200 hills per man-hour where digging and planting are mechanized (Woodhouse, Seneca and Broome, 1974). Dodd and Webb (1975) worked with a variety of species and found that the more difficult plants, giant reed and American bulrush, required about 1 man-hour per 35 hills.

Knutson (1977a and 1977b) summarizes propagule and planting labor requirements for four cordgrasses, (smooth, saltmeadow, gulf, and Pacific) as follows:

Sprigs: 1 man-hour per 100 hills

Peat-pot seedlings: 1 man-hour per 20 hills

Plugs: 1 man-hour per 10 hills

Seeds: About 25 percent as much time as sprigs

Ternyik (1977), using an untrained crew, found the production rate of sedge (three-culm) and tufted hair grass (seven-culm) sprigs to be similar to that reported for the cordgrasses. He felt that this could be substantially improved with experience.

Working hours in the intertidal zone are controlled by tidal regimes. Both harvesting and planting are usually confined to about a 5-hour period per tide. This restriction requires careful coordination for efficient operation and often adds substantially to the cost.

Fertilizer costs are variable but probably no more than \$100 to \$200 per hectare (1978 prices) the year of establishment for conventional materials, including application. Slow-release materials are considerably more expensive.

Cost of temporary protection will vary widely with materials and design. Slat-type sand fence is available at about \$1.50 to \$2.00 per meter f.o.b. factory (1978). Posts and brace material will add about 0.50 to \$0.75 per meter, and installation requires about 1 man-hour per 10 meters. Scrap tires are often available for the hauling but construction labor can be high. Sandbag devices will vary widely with the least expensive designs at less than \$10 per meter.

6. Permits.

Permit requirements to carry out marsh building activities vary from state to state. Dredging, filling, and grading in preparation for marsh planting will usually require one or more permits. Gathering marsh plants or seeds from the wild and marsh planting may or may not necessitate a permit. Information concerning permit requirements and procedures may be obtained from the State Department of Natural Resources, or its equivalent, in the state in which the site or activity occurs or from the appropriate U.S. Army Engineer District.

Permit application and issue procedures are often time-consuming. Permit applications should be initiated well in advance of marsh building activities.

V. SUMMARY

Coastal marshes are valuable as sources of energy, as nursery grounds for fish and shellfish, for storm protection, for trapping sediments, and for accumulating and recycling nutrients.

Marsh planting and restoration is feasible using recently developed techniques. The feasibility of marsh development and the type of marsh at a given site are largely controlled by elevation, slope, degree of exposure, and substrate. Marshes grow on a wide variety of soils. Sands are the easiest to plant and peats are the most difficult. Plant growth is usually best on silts and clays.

The most useful low marsh (intertidal) plants are smooth cordgrass on the Atlantic and Gulf of Mexico coasts, smooth cordgrass plus red and black mangroves in Florida, sedge and arrowgrass in the Pacific Northwest, and Pacific cordgrass on the south Pacific coast.

Important high marsh (irregularly flooded) species are saltmeadow cordgrass, saltgrass, and needle rush on the Atlantic and Gulf of Mexico coasts; these same species plus black and white mangroves in

Florida; saltgrass, tufted hair grass, and pickleweed in the Pacific Northwest, and pickleweed, saltgrass, Jaumea, saltbush, and gum plant along the south Pacific coast.

Marsh plants are propagated by seeds and vegetatively. Seeding is the most economical method, but must be confined to protected sites. Most planting is with vegetative propagules such as sprigs dug from the wild or from nurseries, seedlings grown in peat pots, or plugs taken from the wild.

Seeds are broadcast at low tide and covered by cultivation. Vegetative propagules are inserted by hand or by machine in holes or furrows at low tide. Labor requirements for vegetative planting, including plant acquisition, are from less than 100 to more than 1,000 man-hours per hectare, depending primarily on species, propagule, spacing, and degree of mechanization. Seeding requires only 20 to 50 man-hours per hectare.

Fertilizers are frequently valuable in speeding establishment of new plantings on sandy soils, and are occasionally useful elsewhere. Plantings may require protection from birds and animals and may be damaged by drifting debris.

Newly established marsh plantings require time to develop into mature salt marshes. Full cover and near-maximum primary productivity may be attained in 2 to 3 years.

A tabular summary of regional plant adaptation is presented in Table 1; a planting summary by regions in Table 2.

Table 1. A Summary of Regional Plant Adaptations.

Major Marsh Species	Atlantic	Florida	Gulf	North Pacific	South Pacific	Great Lakes
Smooth cordgrass	1	1	1	5	5	
Saltmeadow cordgrass	1	1	1			
Pacific cordgrass					1	
Gulf cordgrass			9			
Black needle rush	2	2	2			
Big cordgrass	3	3	3			
Bluejoint						4
Common reed	5	5	5			1
Saltgrass	2	2	2	2	2	
Sedge				1		
Tufted hair grass				1		
Seaside arrowgrass				4	4	
Pickleweed				6	6	
Red mangrove		7				
Black mangrove		7				
Minor or Secondary Species						
Sea oxeye	8	8	8			
Marsh elder	8	8	8			
Pickleweed	8	8	8			
Sea blite	8	8	8			
Sea myrtle	8	8	8			
Dropseed	8	8	8			
Panic grass	8	8	8			
Three-square				8	8	
Jaumea				8	8	
Sand spurry				8	8	
Bulrush					8	4
Spikerush					8	8
White mangrove		8				

1. Dominant planted species
2. Widely distributed; difficult to plant
3. Locally abundant; difficult to plant
4. Valuable; planting methods undeveloped
5. Easily planted but possible pest
6. Valuable and easily planted; usually volunteers
7. Dominant species; better planted after initial stabilization
8. Plantable but usually volunteers
9. Replaces saltmeadow cordgrass on heavy-textured substrates

Table 2. Planting summary by regions--Atlantic, gulf, Peninsular Florida, and Pacific.

ATLANTIC, GULF, and PENINSULAR FLORIDA REGIONS

Smooth cordgrass

Propagule	Sprig[1]	Seedling	Plug	Seeds
Elevation	low tidal range, MLW to MHW high tidal range, MTL to MHW			Upper 30 to 50 percent of tidal range
Fetch (km)	<5	<5	<5	<1.0
Salinity ($^{o}/_{oo}$)	< 40	< 40	< 40	< 35
Density	marsh development - 1-meter centers stabilization - 0.3- to 0.6-meter centers			50 to 100 viable seeds per square meter
Date	North, early spring to early summer South, late winter to mid-summer			Spring
Fertilization	N and P first year on sandy or nutrient deficient substrates			Somewhat more responsive than transplants

	Saltmeadow cordgrass	Gulf cordgrass[2]
Propagule	Sprig[3] Seedling	Sprig[3]
Elevation	MHW to extreme high tide	MHW to extreme high tide
Density	0.5 to 1.0 meter on centers	0.5 to 1.0 meter on centers
Date	Spring and early summer	Spring and summer
Fertilization	N and P on sandy or nutrient deficient substrates	None

	Red mangrove[4]		Black mangrove[4]	
Propagule	1 to 2 years	3 to 6 years	1 to 2 years	3 to 6 years
Elevation	MTL to MHT	MLW to MHT	MTL to extreme high tide	
Fetch (km)				
Stabilized	<5	<10	<8	<12
Unstabilized	<1	< 2	<2	< 4
Salinity ($^{o}/_{oo}$)	15 to 40		5 to 50	
Density (m^2/plant)	1	2 to 3	1	2 to 3
Date	Seedlings in late February through March Large plants, year round			

See footnotes at end of tables.

Table 2. Planting summary by regions--Atlantic, gulf, Peninsular Florida, and Pacific.--Continued

NORTH PACIFIC REGION

	Sedge	Tufted Hair Grass	Pickleweed	
Propagule	Sprig[5]	Sprig[5]	Sprig	Seed
Elevation	MT to MHHW	MLHW to EHT	MLHW to EHT	
Fetch (km)	<5	<5	<5	<2
Salinity ($^o/_{oo}$)	0-35	0-35	10-50	
Date	Spring	Spring	Spring	
Density (m^2/plant)	0.25 to 1.0	0.25 to 1.0	0.1 to 1.0	50-100 viable seeds per m^2

SOUTH PACIFIC REGION

	Pacific cordgrass				Pickleweed	
Propagule	Sprig[6]	Seedling	Plug	Seed	Sprig[7]	Seed
Elevation	MTL to MHW			MLHW to MHW	MLHW to extreme high tide	
Fetch (km)	<5	<5	<5	<1	<8	<2
Salinity ($^o/_{oo}$)	<40			<20	<50	
Date	Spring to summer			Spring	Spring and summer	Spring
Density (m^2/plant)	0.5 to 1			50 to 100 viable seeds per m^2	1.0 meter or rooted 0.3 meter	50 to 100 viable seeds per m^2

[1]Intact single-culm plant with roots, not a fragment as is often implied by this term.
[2]Gulf coast only, on cohesive substrates.
[3]Intact multiple-culm plants with roots.
[4]Peninsular Florida only.
[5]Intact multiple-stem plant with roots.
[6]Intact single stem with roots.
[7]Rooted or unrooted cuttings.

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